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INFRARED SATELLITE TECHNOLOGY STUDY
FINAL REPORT

1 December 1982

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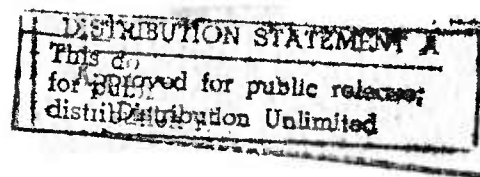Hawthorne, CA 90250

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This is the final report of a support program under which an assessment and evaluation of infrared sensor technology was made, a technology program plan for measurement programs supporting missile surveillance technologies was developed, and technical and programmatic support was provided for ongoing and planned measurement programs. The technology assessment included focal plane, spectral filter, optics, cooling and onboard signal processing

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subsystems for space-based surveillance systems. The measurements
program support included methodology development for program
evaluation, review and analysis of Air Force and other-agency
measurement programs and studies of the implications of advanced
surveillance system concepts for measurement programs.

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1.0 INTRODUCTION

Under contract F04701-79-C-0052, Analytic Decisions Incorporated (ADI) provided support to the Space Division (formerly Space and Missile Systems Organization, SAMSO) of the U.S. Air Force from March 1979 to September 1982. This is the final report for that contract.

The work performed was divided into two general areas. From March 1979 through February 1980, ADI provided an evaluation and assessment of infrared technology and sensors for SAMSO/YC. The scope of the study included both a technical assessment and performance evaluation of all technologies pertinent to infrared earth-looking satellite systems and a projection of future capabilities. This effort was a subtask of the DoD-directed infrared (IR) satellite study.

The two principal results of this study are discussed in Sections 2.1 and 2.2. These cover six major areas of IR technology related to space-based missile surveillance and aerospace vehicle detection (AVD) missions, respectively. This material was developed by ADI while a member of the technology assessment panel of the IR satellite study.

From February 1980 through the end of the contract, ADI provided Space Division (SD/YL) with technical and programmatic support in the development of a Technology Program Plan for Missile Surveillance Technologies and in the evaluation of measurement program options. These wide-ranging activities included methodology development for program evaluation, review and analysis of Air Force and other-agency measurement programs, and studies of the implications of advanced surveillance system concepts for measurement programs.

The four principal studies conducted for SD/YL are discussed in Sections 2.3 through 2.6. These cover the Technology Program Plan, a specific space-based sensor analysis, and two major analyses of near-term (1980's) advanced surveillance system concepts and measurement implications.

In addition to these efforts, numerous shorter-term efforts were conducted throughout the entire performance period. All of these are summarized at an appropriate level of detail in Section 3. The majority are related to measurements program support provided to SD/YL.

A complete list of documents published under this contract is included in Section 4.

2.0 MAJOR STUDIES

During the performance period of this contract, several major studies were undertaken. One or more technical reports were delivered to Space Division covering each of these activities. All of this work is discussed in this section. Contents of the individual reports are highlighted and summarized; the actual reports are listed as references in Section 4.

2.1 Infrared Surveillance Systems Technology Study

From March through November 1979, ADI was tasked by SAMSO/YL to provide an evaluation and assessment of the various technologies pertinent to earth-looking infrared surveillance sensors with emphasis on missile surveillance. This effort was part of the DoD-directed IR Surveillance Systems Study and included a review of the technology base, independent of system constraints, for the state-of-the-art and current and proposed programs.

The technology assessment included the following areas of interest: (1) optics, (2) spectral filters, (3) focal plane, (4) onboard computing, (5) cooling and (6) hardening. The assessment was performed independent of system "drivers". It indicated where then currently funded technology was heading and, to the extent possible, where the technology could go if appropriate funding were made available. The principal conclusions in each of six technology areas are summarized below. The complete report is identified in Reference 1. It should be noted that technology has not been static since this assessment was performed. Consequently, some of the conclusions and projections may now be out of date.

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2.1.1   Optics Technology

Optics technologies were analyzed from the standpoint of fundamental relationships for estimating system parameters in terms of mission requirements and, more to the point, interfaces with other infrared sub-system technologies. It was found that space-qualified optical telescope assemblies suitable for infrared applications are rarely found "on-the-shelf" like camera bodies or lenses. Those which are are apt to be overspecialized left-overs from defunct development programs.

Infrared sensor concepts requiring wider fields-of-view (for wider scene coverage) and larger entrance pupil diameters (for higher sensitivity) are driving optical designers toward radical (untried) configurations which will be more difficult to fabricate, assemble, align and test. At the same time dimensional and weight constraints, imposed by delivery system limitations, are driving mechanical-structural thermal designers toward more flexible and fragile "packaging" at the expense of decreased performance and increased risk.

Table 2.1 summarizes both current (1979) and potential developments in advanced lightweight mirror technology. Improved machining of lightweight mirror cores is an ongoing evolutionary development being driven by program requirements for ever larger but lighter optical elements. A program to demonstrate mirror blank production by FRIT bonding of facesheets to lightweight cores is currently underway. An f/2 sphere of ULE has been produced and polished to ~0.03 waves (r.m.s.). A similar mirror of fused silica will be produced and polished within the next year.

Table 2.1 Advanced Lightweight Mirror Technology

DEVELOPMENTS	COMMENTS
o Improved Machining of Lightweight Mirror Cores	On-going Evolution of Machine Technology
- Fused Silica (Corning Code 7940)	lowest CTE at temperatures between 120 and 170 Kelvins
- ULE^{TM} (Corning Code 7971)	lowest CTE at temperatures between 240 and 740 Kelvins
- Cer-Vit (Owens Illinois, C-101)	low CTE near ambient temperatures, declining availability?
- Zero-Dur (Schott Optical)	similar to, and possible substitute for Cer-Vit
- Beryllium (Brush-Wellman, I-70A)	Highest stiffness-to-weight,highest inhomogeneity and anisotropy in CTE
o FRIT Bonding of Facesheets to Lightweight Cores of Same Material	May require different FRIT (solder-glass) composition for each material.
- ULE	A 20" diam. ULE mirror with spherical front surface is in final figuring.
- Fused Silica	Next step will be a Fused Silica mirror of similar dimensions.
- Other (Cer-Vit or Zero-Dur?)	
o FRIT Bonded Fabrication of Lightweight Mirror Cores	Will a second firing damage joints in a FRIT-Bonded Core?
- Fused Silica	
- ULE	Time-consuming problem is finding and testing solder-glass compositions which match the thermal-mechanical
- Graphite-Epoxy	properties of each material, over the temperature range
- Carbon Fiber-Glassy Carbon Composites	from ambient up to the bonding point and back down to
- Silicon-Carbide Fiber Composites	ambient, or below. (Serendipity in the Chem. Lab?)
- Boron Fiber Composites	
- Organic Fiber Composites	
o Bonding of Fused Silica, or ULE Facesheets to Lightweight Cores of Fiber Composite Materials	More Serendipity, and multiple firings of unlike materials?
o High-Speed, Precision Grinding and Polishing of Mirror Surfaces	Evolution of Machine Control Technology
- With Pre-Programmed Control	short-term development (1985-1990)
- With Real-Time, Interferometric Control	long-term development (2000-?)

*CTE = Coefficient of Thermal Expansion

Fabrication of lightweight cores by FRIT bonding of rib elements and joint posts is being considered but has not yet been funded. The most likely candidates are fused silica and ULE, but some experiments in bonding fiber composites may be considered.

Computer-controlled, high-speed, precision grinding of mirror surfaces is another potential candidate for near-term consideration.

In situ (space) performance characteristics of developmental composite materials are not yet available. Utilization of these materials in telescope components and/or lightweight mirror cores should be considered as high risk. Ceramics (Cer-Vit, Zero-Dur) are credible alternatives to glassy materials (fused silica, ULE, etc.), but have no significant advantages and may be more difficult to obtain. Graphite fiber reinforced aluminum or magnesium may prove to be viable alternatives to beryllium or graphite-epoxy for structural elements of telescope assemblies.

Mirrors weighing less than 20% of equivalent solid are achievable right now (1980), and mirrors weighing only 10% of equivalent solid will be achievable within five years (1985). FRIT bonding of struts (rib elements) into lightweight mirror cores (≤5%) of equivalent solid), together with FRIT bonding of thin facesheets to contour ground cores is currently the only technique which promises mirrors weighing much less than 10% of equivalent solid. Machine-tool loads and speeds must be accurately controlled to minimize the generation of micro-cracks in thin facesheets and micro-fractures in joints between core ribs and facesheets. Faster mirror fabrication depends on advancements in machine control technology,

including specialized sensors, deconvolution algorithms, real-time control algorithms, and specialized mini- or micro-computers.

Optical telescope assemblies with adaptive (active) alignment of rigid (passive) optical elements may be practical within a few years (1985?). Optical telescope assemblies with adaptive (active) control of non-rigid (segmented) optical surfaces (figure control) may not be practical for space applications before the turn of the century (2000+).

2.1.2   Spectral Filter Technology

Several types of filtering techniques suitable for spaceborne operations with various degrees of performance and complexity were investigated. No attempt was made to define the exact operational requirements where specific techniques are optimum; general guidelines were proposed for the application of each technique in relation to its potential mission effectiveness.

Table 2.2 summarizes the eight filter types evaluated, together with some of their more pertinent performance factors. Fixed filters are typically used for broadband radiation sources or for very narrow lines of known wavelength where high transmission is required. The circular variable filter (CVF) is an extension of the dielectric filter and is used to scan out a broad spectral bandwidth with moderate spectral resolution and high transmission. It can also be preprogrammed in steps to interrogate selected wavelength intervals. The AOTF/EOTF is a very broad bandwidth device which can be actively programmed to provide coverage at any wavelength with a desired resolution and transmission. Its

Table 2.2 Spectral Filter Techniques

SPECTROMETER TYPE	PERFORMANCE
FIXED DIELECTRIC FILTER	0.5-40% λ_0 RESOLUTION 0.5-25μm SPECTRAL BANDWIDTH 40-80% TRANSMISSION <10^{-3} OUT-OF-BAND REJECTION LARGE ANGULAR APERTURE
CVF/LVF	25cm^{-1} RESOLUTION, 2-5μm 15cm^{-1} RESOLUTION, 5-8μm 1.0-25μm SPECTRAL BANDWIDTH 40-50% TRANSMISSION <10^{-3} OUT-OF-BAND REJECTION LARGE ANGULAR APERTURE
AOTF/EOTF	5-10cm^{-1} RESOLUTION 2.5-8.0μm SPECTRAL BANDWIDTH 10-25% TRANSMISSION <10^{-3} OUT-OF-BAND REJECTION LARGE ANGULAR APERTURE
GRATING SPECTROMETER	~1cm^{-1} RESOLUTION 2.0-6.0μm SPECTRAL BANDWIDTH 10-20% TRANSMISSION SMALL ANGULAR APERTURE

SPECTROMETER TYPE	PERFORMANCE
FOURIER SPECTROMETER	~1cm^{-1} RESOLUTION 2.0-10μm SPECTRAL BANDWIDTH 10-15% TRANSMISSION VERY SMALL ANGULAR APERTURE
HADAMARD SPECTROMETER	~1cm^{-1} RESOLUTION 2.0-8.0μm SPECTRAL BANDWIDTH <10% TRANSMISSION LARGE ANGULAR APERTURE
FABRY-PEROT ETALON	<10^{-1}cm^{-1} RESOLUTION 10-50cm^{-1} FREE SPECTRAL RANGE 10-20% TRANSMISSION REQUIRES COLLIMATED BEAM
LASER HETERODYNE RECEIVER	10^{-3}-10^{-4}cm^{-1} RESOLUTION ~50cm^{-1} FREE SPECTRAL RANGE DIODE LASER COVERS WIDER RANGE STRINGENT WAVEFRONT MATCHING

main limitation is low transmission, since it is a polarization sensitive device. The grating spectrometer, Fourier Transform spectrometer and Hadamard Transform spectrometer have similar capabilities, but their differences in complexity and the system requirements usually dictate the use of one device or another. The grating spectrometer is relatively simple and does not require complex data reduction, and is usually selected where very high spectral resolution is not required. Both the Fourier and Hadamard Transform devices are optically complex and require a significant amount of data processing and reduction. The Fourier Transform device is usually selected over the Hadamard since the technology is much more developed and data reduction techniques are readily available.

For extremely high spectral resolution over a very narrow range, the Fabry-Perot Etalon or a laser heterodyne receiver are the only choices available. Their primary limitations are a small free spectral range, stringent optical and thermal requirements, and, in the case of the laser heterodyne receiver, a technology which is not well developed. As such, these devices are only used for special purpose requirements where the other spectral filtering techniques become inadequate.

The selection of a spectral filtering technique(s) will depend upon specific mission applications and performance requirements. However, in terms of available and proposed technology developments, several conclusions can be drawn. First, both the fixed dielectric and circular variable filters are fully developed and can be readily applied to any spaceborne application requiring their specific features. The AOTF and EOTF are designed to be fully programmable filters and, as such, both are very high risk development techniques.

A fully working tunable device with the required performance parameters will probably not be available until at least the mid-1980's.

The grating spectrometer is the preferred device where moderate spectral resolution and high throughput are required. The technology is well developed and many units have flown in space. Its major limitation is reduced spectral coverage due to overlapping grating orders. Of the Hadamard and Fourier Transform spectrometers, the latter is by far the better developed. The instrument itself is low risk, however, the mating of a small FTS to a large optical aperture sensor represents a major optical design issue. Also, a mosaic detector array has not yet been mated to an FTS in order to evaluate the optical, spectral, and data rate issues.

The Fabry-Perot Etalon is a very high resolution device and, as such, requires accurate tilt, spacing and thermal control. It also has a fairly limited spectral range unless combinations are used. While this would increase the free spectral range, it would also reduce transmission and degrade mission performance. The heterodyne receiver, except at 10.6 μm is just not developed sufficiently for serious consideration. Even then, the number of laser local oscillators required to operate a sizable mosaic array soon becomes unwieldy. These last two techniques are best reserved for special purpose applications requiring their extremely high spectral resolution.

2.1.3   Focal Plane Technology

Focal plane technology assessments were discussed from the subordinate component level such as detector chips, charge

coupled devices, etc. and the materials and manufacturing processes that impinge heavily on their availability for the infrared surveillance missions. Performance of various materials, both available and projected, and the factors affecting performance were presented with respect to several mission essential parameters, but primarily with regard to the operating temperature of the focal plane sub-system. Intrinsic detector materials and monolithic extrinsic and hybrid focal plane arrays were covered.

Table 2.3 summarizes the typical spectral D*s of a number of detector materials. It shows the useful spectral region of operation of the relevant detector materials. One should exercise some caution in comparing the absolute D* values in this chart since the D* is a function of background. Additionally, extrapolating the D* data to lower backgrounds is in many cases not valid since the detectors may not be BLIP at the specified or lower background.

Most of the detector materials shown in Table 2.3 were assessed for current and projected performance. At the time of this study (1979), InSb appeared to be the most developed and available detector material for near-term hybrid application. Excellent and near theoretical limited performance had been demonstrated at $77^{\circ}K$ with a large quantity of 32 x 32 InSb hybrids. However, its lower operating temperatures and its fixed cut-off wavelength made it less desirable than the alloy detector material such as InAsSb and HgCdTe for many applications where a shorter cut-off wavelength and higher operating temperature are desired.

4 μm cut-off InAsSb appears to be equally developed and available. D* values exceeding 10^{13} cm $Hz^{1/2}W^{-1}$ have

Table 2.3 Detector Material Options for Focal Plane Arrays
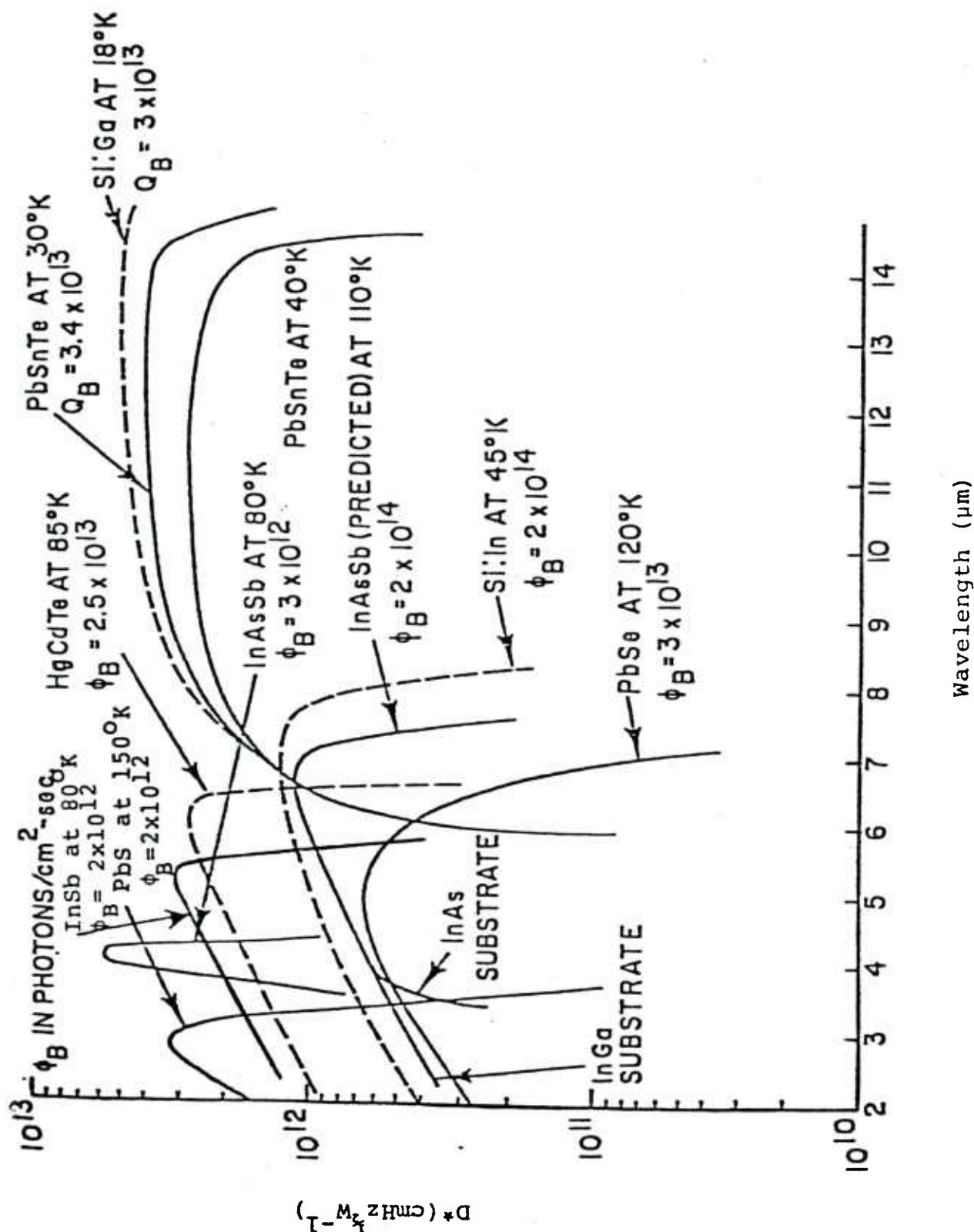
been observed for 32 x 32 arrays. However, because the lattice mismatch increases as the Sb fraction is increased, comparable performance has not been obtained with longer wavelength cut-off compositions of this alloy.

PbS is a thin film photoconductive detector material which has been widely utilized in the past 10 years. Considerable development effort has recently focused on PbS deposition and delineation techniques for mosaic focal plane applications. The pulse-biased mosaic and stacked ceramic focal plane approaches have both evolved into viable near-term techniques to fabricate mosaic focal planes.

R_oA product and D* data obtained on 2 μm HgCdTe indicate that performance close to the theoretical g-r limit can be obtained in the 140 to 250°K range for these diodes. One can expect similar results for 3 μm cut-off. Uniformity measurements further show that the responsivity, noise, R_oA and D* uniformity are comparable to InSb and InAsSb arrays.

While performance close to the g-r limit can be obtained with SWIR and MWIR HgCdTe in their respective temperature range of operation, the performance of current long wavelength cut-off (λ_c>10 μm) HgCdTe diodes is close to two orders of magnitude below the theoretical g-r limit. The strong dependence of R_oA on detector area as well as the R_oA dependence on temperature suggest that surface leakage is the primary limiting mechanism. The surface leakage is thought to be related to material defects at or near the surface, part of which is a result of processing damage. Processing improvements and the use of field plates or guard rings can be expected to reduce leakage effects. However, this will be a long-term prospect.

Comparison of the various focal plane approaches indicate at this stage that both the monolithic extrinsic and hybrid approach can be the basis for a two dimensional mosaic array. The monolithic extrinsic, in principle, should in the long run be more amenable to the incorporation of on-chip signal processing functions such as AC coupling. Additionally, it is potentially the lowest cost of the approaches since its fabrication utilizes standard silicon LSI processing. On the other hand, the low operating temperature requirement can have a significant system impact since a cryo-cooler is required for a long life mission.

The hybrid is the preferred choice where the attributes of the intrinsic detector array, i.e. higher operating temperature and quantum efficiency, low crosstalk, and tunable cut-off wavelength are important considerations.

2.1.4 Signal Processing

The signal processing assessment included both hardware (integrated circuit chips) and software (algorithms and/or techniques) for onboard signal processing. It covered the application of decision-making and information-extraction techniques to IR detector array outputs before transmission of data to the ground. Related data handling functions such as multiplexing, A/D conversion, encryption, command, control, etc. were not included in the study. A summary of VLSI device technology with risk as a major parameter was provided as well as comparisons and projections of LSI device technology availability. These were presented in general in terms of device specifications and performance data. The processing techniques (algorithms) were described functionally and did not include detailed mathematical descriptions of their operation.

Data on IC characteristics were assembled from a
variety of sources, principally open literature, about
commercially available products and manufacturing techniques; a
list of algorithms suitable for advanced IR sensors was
compiled after study of several current or proposed sensor
programs. It should be noted that to date only simple
thresholding has been used for space-based processing.

Table 2.4 summarizes current (1979) projection of VLSI
device technology expected to be available in the 1983-85 time
frame and associated risk. The projections were made by RADC.
An unstated characteristic of the devices covered in the Table
is that channel line widths, currently 3-5 μm, are expected to
shrink to 1 μm or even less by 1985. A total systems design
approach including overall data flow, real-time processing
requirements and cost would be needed to make specific device
selections for space-based use. In particular, radiation
hardness will be a major consideration. With adequate military
funding, availability of hardened ICs is estimated to be a
medium risk by the mid-80's and (with continued funding) a low
risk by 1990.

A wide variety of processing algorithms have potential
application to onboard reduction of data from large focal plane
arrays. Based on a comparison of several planned advanced IR
sensor processing schemes, the techniques listed in Table 2.5
were assembled. The level at which these algorithms have been
verified ranges from computer simulation to operational usage
with actual satellite sensor data.

Since staring sensors have not been flown in space,
performance curves for the various algorithms are based mainly
on computer simulation. Thus, the near-term risk associated

Table 2.4 Summary of VLSI Device Technology in 1983-1985

	Low Risk	Medium Risk	High Risk
LOGIC			
Technology	Bipolar, NMOS	CMOS/SOS,I^2L	GaAs FET
Speed-Power product (fJ)	100	50	1(77°K)-10(300°K)
Gate delay (ps)	200	500 1000	50
Integration Level (# gates)	100K	50K	10K
FAST MEMORY			
Technology	Bipolar, NMOS		GaAs FET
Integration level	65K/chip		20K/chip
Power (w)	1/2		?
Access time (ns)	10		?
DYNAMIC RAM			
Technology	Bipolar, NMOS	CMOS/SOS	Bipolar, NMOS
Integration Level	256K/chip	128K/chip	2M/chip
Power (w)	1/2		1
Access time (ns)	80	100	80
SERIAL ACCESS MEM			
Technology	CCD Bubble		CCD Bubbles
Integration Level	1M/chip 1M/chip		8M/chip 10M/chip
Power (w)	1 1		1 1
Latency time (µs)	200 1000		500 4000

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Table 2.5   Summary of Signal Processing Techniques
Used or Planned for Advanced IR Sensor Programs

o   TEMPORAL DIFFERENCE FILTERING (STARING SENSOR)

   •   FIRST, SECOND OR THIRD ORDER

o   THRESHOLDING

   •   ADAPTIVE
   •   TIME-PHASED, MULTI-LEVEL
   •   TWO-SIDED

o   SUPERPOSITION (INTEGRATION) OF MULTIPLE FRAMES OF
    FILTERED DATA

o   TEMPORAL AND SPATIAL CORRELATION

   •   STATIC TARGET IDENTIFICATION (SCANNING SENSOR)
   •   TRACK DETECTION AND PREDICTION ("N OUT OF M" TEST)
   •   RECURSIVE FILTERING (KALMAN, ETC)
   •   TARGET TYPING

       •   TRACK TEMPLATE MATCHING
       •   INTENSITY-TIME HISTORY MATCHING

with onboard processing for these sensors is greater than, say, that associated with moving ground-tested processing algorithms onboard the currently operational surveillance system. Also, the simulations are only as good as the phenomenology models which they employ. A continuing level of background measurements programs is needed to expand the available data base (especially with regard to the wavelengths and viewing conditions relevant for space-based sensors) and to reduce the risk associated with algorithm performance validation. After 1985, if planned staring sensor programs proceed on schedule, the staring sensor algorithms will have been exercised in orbit, and the risk can be reassessed. For the near-term (1985), planned experimental sensor programs are estimated to make OBSP a medium risk in terms of achieving planned goals in that time frame; without any experimental programs, the risk will remain high.

2.1.5 Cryogenic Technology

Background data, description and operation of various refrigeration cycles, performance data, and development potential were summarized for a number of refrigeration concepts adaptable to spaceborne operations. The highlights of various concepts were briefly defined, some of the more significant operating characteristics were indicated, and basic integration limitations with the entire spacecraft were outlined.

The various types of coolers were segregated into four fundamental categories:

(1) Open cycle, expendable systems which use: stored cryogens in either the subcritical or supercritical liquid state; solid cryogens; or stored, high pressure gas with a Joule-Thomson (J-T) expansion.

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(2) Passive radiators which cool systems to cryogenic temperatures by radiation to the low temperature, deep-space environment.

(3) Closed-cycle, mechanical-refrigerator systems, which provide cooling at low temperatures and reject heat at high temperatures.

(4) Thermoelectric coolers which use the Peltier cooling effect.

The types of systems which the technology assessment addressed were expected to have operating temperatures in the range of $70^{\circ}K$ to $170^{\circ}K$, cooling requirements of one to several watts, and mission durations on the order of three to five years. For these reasons, the open cycle and thermoelectric cooling systems were excluded from further consideration. The assessment, therefore, addressed only passive radiator and closed-cycle, active cooling systems.

Figure 2.1 can be used as an aid in selecting the type of cryogenic refrigerator system for use in a given application. Three primary variables (temperature, refrigeration capacity, and mission duration) are required in most cases to properly identify the most desirable system. The figure on the left shows refrigeration capacity in watts versus mission duration in days. The figure on the right shows refrigeration capacity versus refrigeration temperature ($^{\circ}K$). It should be clearly noted that these merely represent guidelines and in many cases, especially where regimes are in close proximity or even overlap, additional criteria such as booster payload capability, geometry limitations, type of orbit, the reliability required, the development cost and time

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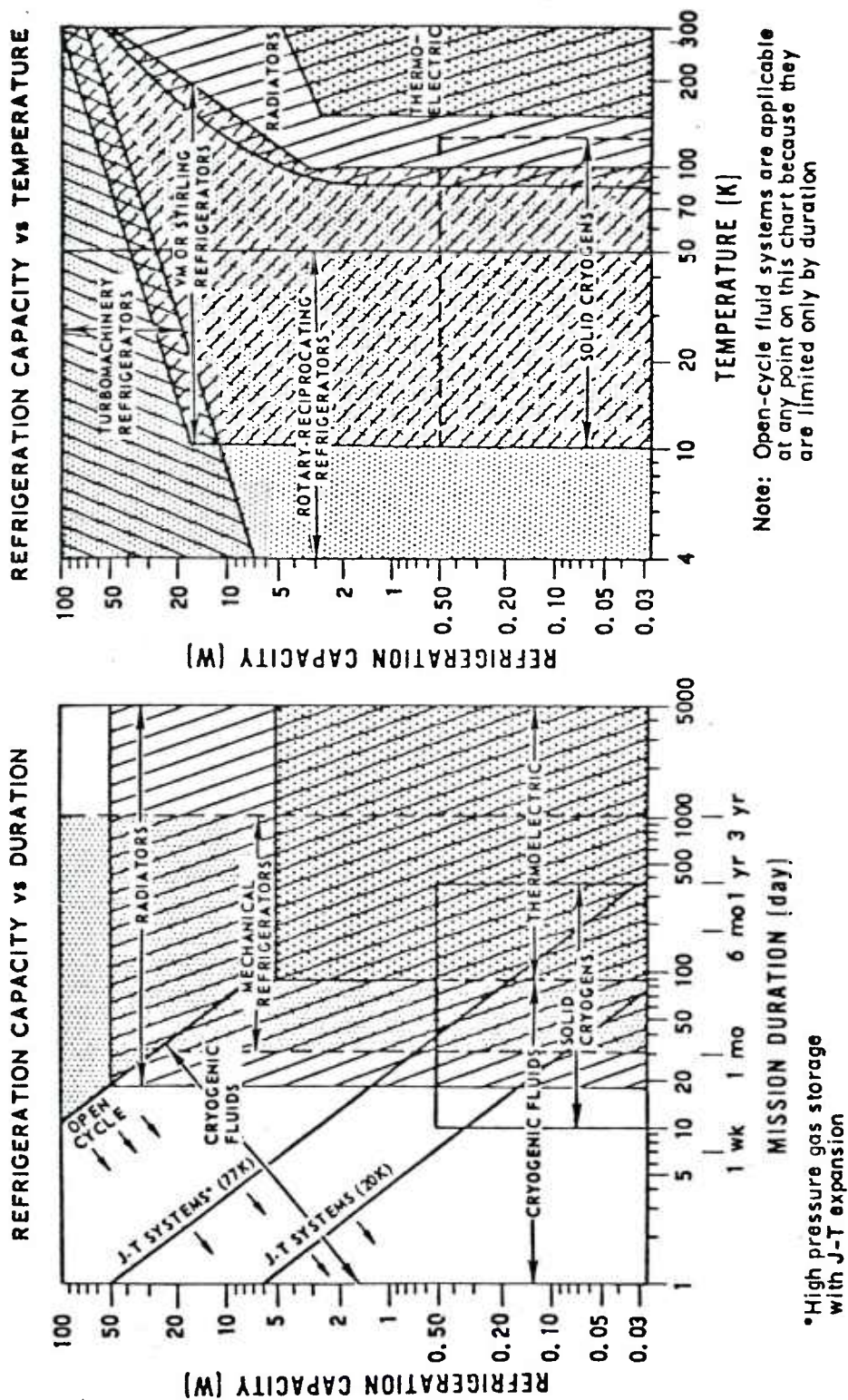
Figure 2.1 Cryogenic System Selection Guidelines

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available, etc., will determine which system is most appropriate. These charts are based upon the technology that either exists (1979) or is under development to the point at which a given system can be applied in the next three to five years.

For temperatures above about $100^{\circ}K$ passive systems utilizing radiators become attractive, especially where long mission durations are involved. Mechanical refrigerators are applicable over a wide range of conditions from about $4^{\circ}K$ to near $100^{\circ}K$ at moderate capacities and possibly to higher temperatures at relatively higher capacities.

There are two major risk areas associated with all of the active cooler technologies. First, each active cooler technology currently has only one developing contractor. Continued cooperation and maximum effort by each of these contractors is critical to technology development unless alternate sources are found. Second, the vibration levels which will be produced by these machines is, as yet, unknown. Vibration levels can be reduced significantly by good engineering design. However, precision line of sight stability will be required for any advanced mosaic sensor concepts.

Passive radiant coolers utilizing the low temperature sink of space directly produce an attractive, completely passive cooling system capable of high reliability for extended periods. Utilization of this cooling technique should continue to increase especially for temperature requirements in the range of 120 to $190^{\circ}K$. Since the requirement for viewing deep space is critical to passive radiator performance, satellite system orbital characteristics will be a driver in the selection and design of this type of system. Many types of passive radiator coolers have been developed and flown successfully in space for many years.

2.1.6   Laser and Radiation Effects

A brief examination was made of the effects of and the hardening techniques against natural, nuclear, and laser irradiation. The data was divided into two parts: radiation hardening and laser hardening/vulnerability. Radiation hardening covered primarily current (1979) and projected hardness levels for the different LSI technologies. For reference, expected doses for geosynchronous and elliptical orbits were given as functions of spacecraft shielding thickness and times in orbit.

The laser hardening part began with a summary and discussion of generic CCM techniques. Data was then presented comparing the performance of different optical switching techniques and discussing laser damage levels for detector and mirror materials. The hardening of solar arrays was briefly addressed.

Table 2.6 summarizes the current (1979) status of LSI technologies for radiation hardness. Hardness development programs generally evolve in those LSI technologies which are commercially successful for other reasons (like good speed-power product or gate-density characteristics). Having a commercial technology base on which to build a hardening program ensures a reliable, uniform, readily available end product usually at reasonable cost. It should also be noted that military requirements span a much wider range than simply radiation hardness. Thermal, shock, vibration, and reliability requirements must be satisfied simultaneously with hardness to radiation. In general, the application of LSI technologies to space-based memory devices is the most stressing development problem because of information loss during periods of transient radiation.

Table 2.6   Summary of Radiation Hardness Characteristics
of LSI Technologies

o ' GENERAL ISSUES

  - HARDNESS CONSIDERATIONS INVOLVE TWO DIFFERENT EFFECTS:
    TOTAL DOSAGE (NATURAL SPACE RADIATION) AND TRANSIENT
    EFFECTS (WEAPONS-RELATED).

  - HARDNESS PROPERTIES VARY WITH DEVICE TYPE AND OPERATING
    TEMPERATURE.

  - NON-VOLATILE MEMORY TECHNOLOGIES ARE REQUIRED FOR GOOD
    TRANSIENT EFFECT HARDNESS.

o HARDNESS ASSESSMENT SUMMARY FOR SPECIFIC TECHNOLOGIES

  - CMOS/SOS   -- GOOD POTENTIAL FOR SPACE RADIATION HARDNESS
                   ARTIFICALLY NON-VOLATILE MEMORY CAN BE
                   DEVELOPED.

  - CMOS   -- SPACE RADIATION HARDNESS DEMONSTRATED

  - NMOS   -- HARDENING TECHNIQUES NOT DEVELOPED

  - I^2L -- GOOD POTENTIAL FOR SPACE RADIATION HARDNESS

  - TTL,ECL   -- INTRINSICALLY HARD TO SPACE RADIATION

  - MNOS   -- EXCELLENT POTENTIAL FOR SPACE APPLICATIONS
                   (NON-VOLATILE)
                   TECHNOLOGY IMMATURE, EXTENSIVE DEVELOPMENT
                   REQUIRED

  - MAG. BUBBLE-- GOOD POTENTIAL FOR SPACE RADIATION HARDNESS
                   ASSOCIATED CIRCUITRY NEEDS TO BE HARDENED

  - CCD   -- HARDENING TECHNIQUES NEED DEVELOPMENT
                   N-BURIED CHANNEL DEVICE BEST FOR TOTAL DOSE;
                   SURFACE CHANNEL DEVICE BEST FOR NEUTRON FLUX

With adequate military funding, availability of the space radiation hardened ICs needed for advanced sensor systems was estimated a medium risk by the mid-80's and (with continued funding) a low risk by 1990.

To investigate and develop survivability concepts against high energy laser (HEL) threats, the Air Force has funded the Satellite Material Hardening (SMATH) program since 1976. The completed SMATH-II program developed hardening devices for various satellite systems using nonlinear materials. The optical system survivability concepts were developed for a large aperture IR telescope, an operational linear scanner, and an atmospheric burst locator. The current component demonstration effort is applying selected techniques to develop performance qualified hardened sensor system components.

Hardening a sensor to laser radiation is a complex, system-level problem. Earlier, a list of techniques was given which apply to sensor optics, filters, detectors, and signal processing. It should be remembered that no single technique ensures survivability. In light of the damage level data presented in this section, the table summarizes some generic choices for hardened sensor components. Monolithic focal planes and optical switches (or tunable filters) represent a medium to high risk in terms of availability by 1985. Current approaches to laser hardening for advanced sensors usually center around relatively easy, low risk techniques (like adding baffling, all-reflective optics, multiple detector types) or a single medium to high risk advanced technology component (like optical switches, tunable filters). Complete systems-level design approaches for laser hardening have not been performed. Consequently, the overall risk involved in designing a laser-hardened sensor for either near-term or far-term usage is unknown.

2.2   Aerospace Vehicle Detection Technology Study

From September through February 1980, at the direction of SAMSO/YC, ADI examined the requirements for IR technology to perform the AVD mission. This represented a special case of ADI's ongoing evaluation and assessment of the various technologies pertinent to earth-looking infrared surveillance sensors with emphasis on missile surveillance.

A report, summarized below, was assembled in order to highlight IR technology issues especially relevant to AVD. It was hoped that the material would be a useful guide for further refinements of the technology requirements for AVD and, in particular, for developing a realistic basis for future AVD studies. The complete report is identified in Reference 2.

Section 2 of the report presented current (1979) estimates of the technology requirements for AVD relating to detectors, coolers, optics, and signal processing. At the time of the study, neither the target class, time frame, nor design approach was known for sure. Since the target class is a strong driver for certain technology requirements, three levels were given for them (level I for bombers only, level II including small aircraft and large cruise missiles, and level III for the smallest cruise missiles). While these requirements will evolve in time, they could be used as a baseline to evaluate the suitability of available technologies for the AVD mission.

The optics technology in Section 3 emphasized constraints, both theoretical and practical, associated with obtaining telescope apertures of a given size. The assessment concentrated on geometrical requirements, physical

phenomenology and technological limitations as constraints imposed upon "aperture". It was not possible to address several other significant issues associated with this application within the time-scale of this study. One issue which deserved more attention was the development of techniques for step-staring and their impact upon the mechanical-structural design of optical telescope assemblies. Sensor concepts involving wide-angle stepping with short settling (and vibration damping) times may impose severe constraints on aperture because of weight increases necessitated by increased requirements on structural rigidity (stiffness) and mechanical isolation of vibrations induced by fast stepping motions of "agile" mirrors.

Section 4 showed the photon noise level of different detector types applicable to the AVD mission as a function of detector characteristics, operating temperature, and background flux levels. These covered operating regions expected for MWIR and LWIR photovoltaic HgCdTe, photovoltaic InSb and extrinsic Si:In mosaics. The maximum allowable detector noise for the three target classes was indicated.

Also discussed were the properties of two AC-coupling schemes for background rejection. Both approaches can, in principle, provide the background rejection necessary to circumvent the CCD register limitation. One approach incorporates a monolithic coupling capacitor and a reset switch. The coupling capacitor isolates the detector bias from the input network. Charge saturation of the CCD register is prevented by periodically resetting the input gate. The second approach implements background rejection by utilizing a CCD fill and spill network operating in a finite difference mode.

Section 5 addressed two specific areas related to signal processing. For staring sensors, one measure of the extent to which clutter can be suppressed is the clutter equivalent target. This quantity was defined parametrically in terms of background scene and sensor parameters. In addition, temporal difference filtering was discussed along with other techniques including multi-threshold detection and average value differencing. The region of utility of these and other possible approaches was presented as a function of clutter velocity.

The three other technologies above (filters, coolers, hardening) did not require special treatment and therefore were not discussed in detail in this report. Current status and likely future developments in these areas were covered in Reference 1.

2.3   Technology Program Plan for Missile Surveillance Measurements

Beginning in February 1980, ADI was tasked by SD/YL to prepare a draft Technology Program Plan (TPP) for missile surveillance measurements being conducted under USAF Program Element 63424F, Missile Surveillance Technology. The original TPP with supporting annexes was published in November 1980. Subsequently, the first annual revision to the TPP was prepared during calendar year 1981 and published in November 1981. All of these reports are listed in Reference 3.

The purpose of the TPP was to provide a clear definition of measurement program goals and the plans for achieving these goals. The overall approach used, based on Space Division inputs, in developing the TPP is shown in Figure 2.2. After assembling a large data base pertaining to

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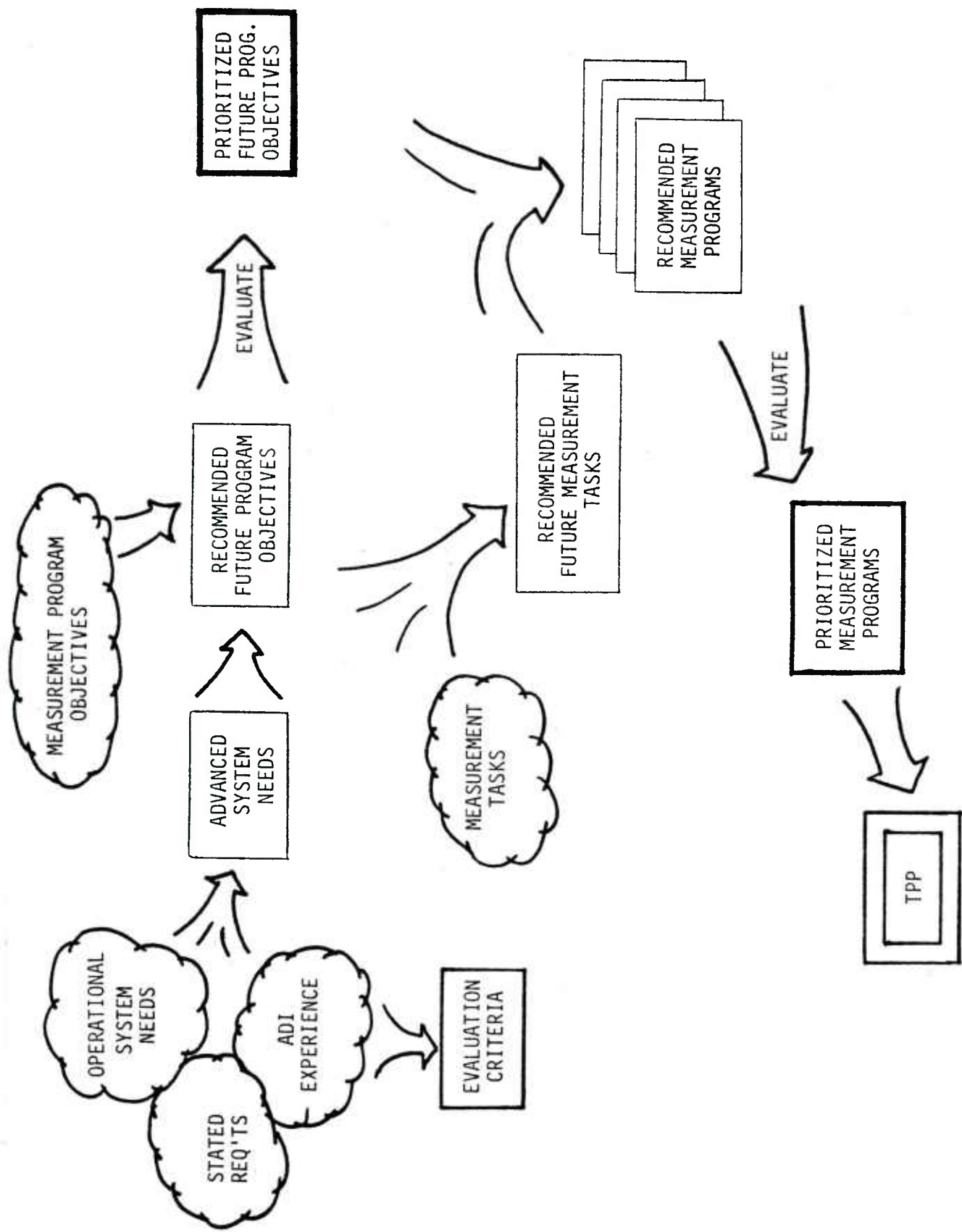
Figure 2.2 Approach to Developing the TPP

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missile surveillance measurements, ADI developed a set of objectives for measurement programs supporting the design of advanced space-based infrared missile surveillance systems. These program objectives as well as actual measurement programs being conducted or planned under PE63424F were prioritized by a government committee using a methodology developed by ADI. All of this material along with supporting information was published in the referenced documents. The following subsections highlight the major areas of work associated with developing the TPP.

2.3.1 Data Base Material

To place the TPP development on a firm foundation, an extensive data base was assembled. One major section contains detailed information on 24 DoD infrared measurement programs. This subset of completed, in-progress, and planned measurement programs was selected by estimating how relevant the measurement program would be to future "down-looking" space-based infrared surveillance sensor concepts performing the missile early warning and attack assessment missions. The assembled data includes program objectives, schedule, sensor viewing conditions (background and targets), sensor characteristics, results (if any) of the measurements and references. The objectives of these programs were used as one input in developing a list of general (ideal) measurements program objectives as discussed later.

A second major component was a compilation search of various official Air Force documents for statements of need which should be addressed in future measurement programs. The types of documents covered included Mission Element Needs Statements, Statements of Need, and Program Management Directives. Excerpts of the documents were included in the

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data base. Before the TPP was published, the reference list was expanded to include appropriate contractor reports as well if they provided credible sources of measurement needs.

To provide some general guidance on the types of support that future surveillance systems might need for concept evaluation, several such concepts were examined and included in the data base. The concepts included both staring and scanning systems and helped to define the types of target and background data most needed from measurement programs.

Another important aspect of measurement programs discussed is support of model development and validation. Included in the data base were model development status and supporting measurement needs for seventeen IR observables associated with strategic missile surveillance. The observables cover all aspects of missile launch and flight except re-entry. In most cases, the measurement needs were closely allied with those identified on the basis of future surveillance system concepts and "official" statements.

Other categories of information related to PE63424F included in the data base are Memoranda of Agreement, Acquisition Plan, and Security Classification Guide.

2.3.2   Program Objectives and Task Definition

On the basis of the material described in the preceeding subsection, generic types of "needs" were identified for advance missile surveillance systems. These are shown in Table 2.7. The generic nature of Table 2.7 allows wider applicability of these needs than to just the specific surveillance concepts included in the data base.

Table 2.7   Generic Measurements Needs for
            Advanced Infrared Surveillance
            Sensor Concepts

- Background Data (Multispectral, two-dimensional)

    - Wide variety of earthscenes under "average" conditions

    - Earthscenes under transient conditions (effects of weather, etc.)

    - Limb (airglow, aurora, etc.)

    - Nuclear effects

    - Solar scattering and reflection phenomena

- Target Data (Multispectral, domestic and foreign targets)

    - ICBM and SLBM signatures

    - PBV signatures

    - Staging effects

    - RV signatures

- System/Technology Demonstrations

    - Staring sensor concept

    - New hardware components

    - On-board processing

    - Laser-induced effects

    - Space shuttle platform utility (for measurements)

- Analysis of Measured Data to Define Needed Improvements in Data Collection

    - Evaluation of data utility for analyzing clutter suppression algorithms

    - Evaluation of data utility for analyzing target detection and tracking algorithms

The needs in Table 2.7 were translated directly into
the set of general measurement program objectives shown in
Table 2.8. This high-level grouping of objectives was designed
to introduce an overall order into the wide array of
requirements found in the data base. The philosophy behind
Table 2.8 was what would one desire to know prior to designing
a next-generation surveillance system given unlimited time,
resources and the cooperation of foreign targets. Thus, these
objectives are labeled as "ideal".

For each of these nine general objectives, a set of
two to seven specific ("ideal") objectives was developed. As
an example, for general objective 1 (staring earthscene data),

Table 2.8   Ideal General Measurement Objectives
(Unprioritized)

1. GLOBAL STARING BACKGROUND DATA COLLECTION OF TYPICAL EARTH
   SCENES (STATISTICS OF THE ORDINARY/BENIGN CONDITIONS AGAINST
   WHICH THE SYSTEM MUST OPERATE) AS WOULD BE VIEWED BY THE
   SPACEBORNE SENSOR.

2. GLOBAL STARING BACKGROUND DATA COLLECTION OF TEMPORALLY
   DYNAMIC EARTH SCENES (WORST CASE TYPE CONDITIONS CAPABLE
   OF GENERATING FALSE ALARMS).

3. BACKGROUND DATA COLLECTION OF DYNAMIC BACKGROUNDS AND
   ATMOSPHERIC EFFECTS IN THE ATH LIMB-VIEWING GEOMETRY.

4. DATA COLLECTION OF NUCLEAR EVENT EFFECTS ON EARTH'S
   BACKGROUND.

5. FOREIGN PBV PLUME SIGNATURE DATA COLLECTION AND PREDICTIVE
   CAPABILITY DEVELOPMENT (IGNITION THROUGH RV DROPS).

6. FOREIGN ICBM/SLBM 2ND STAGE PLUME SIGNATURE DATA COLLECTION
   AND PREDICTIVE CAPABILITY DEVELOPMENT/REFINEMENT.

7. FOREIGN RV COLD BODY SIGNATURE DATA COLLECTION (PBV RELEASE
   TO RE-ENTRY).

8. SYSTEM/TECHNOLOGY EXPERIMENTS.

9. ALGORITHM/ADVANCED COMPUTER ARCHITECTURE ANALYSIS FOR
   MEASUREMENT DATA IMPROVEMENT.

the specific objectives called for measurements to ascertain background signatures showing variations due to diurnal, seasonal, geographic, high-gradient interface areas (land/sea, etc.) and sea-state effects.

Finally, for each specific objective a set of measurement conditions under which the objectives needed to be fulfilled was specified. In this way, (ideal) measurement tasks were defined. Table 2.9 shows this task set for general objective 1. The "TBD's" signify cases where surveillance system concept development was not firm enough to specify hard numbers. These cases will be filled in as the concepts evolve.

Having defined a complete set of desired measurement objectives and measurement tasks to satisfy these objectives, the correlation was made between ongoing and proposed measurement programs and the set of ideal tasks. For example, as of 1980, experiments planned for the Balloon Altitude Mosaic Measurement (BAMM) program addressed specific objective D in Table 2.9. Subsequently, experiments addressing objectives A and C were also planned. It was found that, by including the measurement programs being conducted or planned under PE63424F and the Air Force Geophysics Laboratory (AFGL) programs CIRRIS, ELIAS and the KC-135 aircraft, all of the ideal tasks except those associated with re-entry vehicles were being addressed at some level.

2.3.3 Prioritization and Program Rating Methodologies

In order to focus the large number of ideal tasks defined in the TPP, some type of prioritization scheme was desired. ADI developed a two-step process to accomplish this in which first the general objectives and then the specific objectives were separately prioritized.

GENERAL OBJECTIVE 1.		STARING BTH BACKGROUND DATA COLLECTION OF SELECTED TYPICAL EARTH SCENES (STATISTICS OF THE ORDINARY/BENIGN CONDITIONS AGAINST WHICH THE SYSTEM MUST OPERATE)										
CONDITIONS / **SPECIFIC OBJECTIVE**	MODE (SCAN, STARE, ETC.)	SCENES VIEWED	TOTAL FOOTPRINT/PIXEL FOOTPRINT (N.MI. X N.MI.)	NESR (W/SR -CM²μM)*	FREQUENCY DOMAIN (Hz)	MEASUREMENT DURATION	SPECTRAL REGIONS Nλ (MICRONS)	RADIOMETRIC ACCURACY (%/DYNAMIC RANGE) (10^n)	SOLAR SCATTERING ANGLE (°)	DESIRED PLATFORM ALTITUDE	SCENE SMEAR (%)	
A. Measure day, night and terminator earth scenes	STARE DITHER	LAND MTNS. OCEAN	16 X 16 / .5 X .5	TBD	0-20	60 SEC	2.7 4.3 6.3	30% / 10^5	$5° \le \theta \le 90°$	>150KM	<10%	
B. Measure typical summer, fall, winter, spring backgrounds over similar geographic areas	STARE SCAN DITHER	LAND MTNS.	16 X 16 / .5 X .5	TBD	0-20	30 SEC	2.7 4.3 6.3	30% / 10^5	$15° \le \theta \le 90°$	>150KM	<10%	
C. Measure backgrounds of the north corridor, snowfields, mountains and other geographic areas.	STARE DITHER	SNOW ICE	16 X 16 / .5 X .5	TBD	0-20	60 SEC	2.7 4.3 6.3	30% / 10^5	$5° \le \theta \le 90°$	> 150KM	< 10%	
D. Measure selected interface areas to include land/sea, ice/sea, etc.	STARE DITHER SCAN	LAND WATER SNOW ICE	16 X 16 / .5 X .5	TBD	0-20	30 SEC	2.7 4.3 6.3	30% / 10^5	$5° \le \theta \le 90°$	>150KM	10%	
E. Measure ocean in several sea states (out of specular region).	STARE DITHER SCAN	OCEAN WAVES	16 X 16 / .5 X .5	TBD	0-20	30 SEC	2.7 4.3 6.3	30% / 10^5	$15° \le \theta \le 90°$	>150KM	10%	

*   NESR to be sufficient to allow variations to be measured commensurate with a 10 watt/sr. target.

A set of seven evaluation criteria, shown in
Table 2.10, were developed for prioritizing the general
objectives. These criteria represent a spectrum from direct
systems applications to exploratory research. To utilize
these, arbitrary maximum numerical values were assigned to each
criterion. The set of selected values was 20, 25, 10, 15, 10,
5, and 15 for items 1 to 7 in Table 2.10, respectively. Each
general objective was analyzed against each of the seven
criteria, receiving a value representing how much it
contributes to that criterion. Awarding of the maximum value
would indicate that the particular general objective is of
primary importance in satisfying that particular category,
whereas a value of 0 indicates that it contributes nothing.
The overall priority of the given general objective is then
obtained by totalling the values awarded under each criterion.

For the specific objectives, the prioritization scheme
involved ranking these separately for each general objective.
The most important specific objective under each general
objective was assigned a value of 10 with the remaining
specific objectives being assigned a value between 0 to 10.

Effective use of this two-step objective/task
prioritization procedure depends critically upon the individual
or group doing the rating. An in-depth understanding of the
general and specific objectives and how they relate to advanced
surveillance system design is required. To arrive at the final
prioritized measurement program objectives reported in the
Technology Program Plan, an evaluation team comprised of
individuals in AFSD, AFGL, Aerospace Corporation, AFRPL and FTD
was used. Individual ratings for each general and specific
objective were averaged to reflect a group consensus.

Table 2.10   Criteria for the Evaluation and
             Prioritization of General Measurement
             Objectives

The following are the considerations in prioritizing measurement objectives, as they relate to, or provide input for, systems design, the general body of knowledge, etc.

1. Feasibility of Concept or Stated Requirements. Is the particular objective aimed at determining whether an AF/DoD mission requirement can or cannot be accomplished? Is a particular concept feasible?

2. Design of Operational System. Will satisfaction of the objective provide key design parameters for the system? To what extent does the successful deployment of the system depend on obtaining those parameters?

3. Optimization of Current or Future System. Will satisfaction of the objective provide the ability to optimize the operation of a current system or design of a future system? Will the objective allow final "tweaking" of certain parameters to gain optimum system performance?

4. Validation of Concept or Hardware. Does the objective provide for a validation of a concept or hardware component important to a future system? Can it be used to run simulations and/or test algorithms, etc.?

5. Expand Body of Knowledge. Does the objective provide for a general expansion of the body of knowledge associated with missile surveillance? Does it provide input to atmospheric modeling codes? Plume codes? Etc.?

6. Exploratory Research. Does the objective potentially lead to new concepts or technologies?

7. Uniqueness. Has the objective been the subject of past or present measurement programs? Does the data already exist? How much new information will be obtained by satisfying this objective?

The detailed results are presented in the first two reports listed in Reference 3 and represent the current best effort at creating order and a cognizance of relative priorities among the numerous objectives for measurements supporting a future missile early warning and attack characterization system. Their utility in developing and evaluating a program plan stems from the fact that each specific objective is ordered with respect to others in the same general area, and its parent general objective is ordered with respect to the others. This information provides the program manager with at least a first-order ability to both develop new measurements efforts and evaluate proposed and ongoing projects within a framework that emphasizes the relative importance of objectives.

To provide corroborating information on the objective and task prioritization results, at the request of YLVM, ADI organized a meeting of representatives from aerospace companies which deal with advanced infrared missile surveillance systems. The same prioritization methodology developed for the government evaluation team was used by the industry representatives. Ratings were scored and averaged as before and reported to YLVM. The results, while reflecting a somewhat wider range of opinions, were remarkably close to those arrived at by the government and published in the TPP.

It was pointed out in the preceeding subsection that ongoing and proposed measurement programs were addressing virtually all of the ideal tasks associated with listed specific objectives. Analogous to the prioritization of objectives described above, it was desired to rate actual measurement programs for their utility in meeting the needs of advanced surveillance systems. Such a rating was required for sound program management.

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To accomplish this rating in a reasonably objective manner, a series of factors were developed to describe various aspects of measurement programs. These took into account: 1) the prioritization factors associated with all of the general and specific measurement objectives which were addressed by the program; 2) how well the program performed against the requirements or conditions specified for the ideal tasks; 3) how important particular requirements addressed by the program were considered at various levels within DoD; 4) program do-ability or the risk inherent in the program; 5) the timeliness of the results of the measurement program as far as influencing advanced surveillance system design was concerned.

For each factor, a numerical rating scheme was developed to allow consistent and objective evaluation of a complete spectrum of measurement programs. An overall program utility factor was then calculated by averaging the product of all the individual factors over the separate objectives treated by the program. Again, the final rating (Reference 3) was performed by individuals knowledgeable in the various program areas, utilizing as accurate an estimate of the sensors, platforms, and general experimental configurations as was available. While the results must be viewed as a first best estimate, as the program plans are firmed up and more detail is available, these evaluations will be similarly updated to reflect a more comprehensive analysis.

Yet another level of insight into the relative merits of the various programs was accomplished in the above evaluation framework by introducing cost. Cost was utilized to estimate the return on one's investment. In this framework, return-on-investment (ROI) was calculated by dividing the utility factor by program cost in millions of dollars. This

resulted in an ROI quantity defined as utility per million dollars invested, and provided a different framework within which to view the relative merits of the programs.

2.3.4   Program Roadmaps and Supporting Information

The planning process outlined above included developing program objectives, potential measurement tasks, prioritizing these and rating actual measurement programs for their utility in achieving these objectives. Since these objectives and programs are necessary for the development process of future missile surveillance sensor systems, the program development process was carried one step further and they were integrated into a complete program plan which formed the basis for the Space Division FYDP budget. Timelines and relationships between these programs were depicted on two roadmaps covering background and target signature measurements, respectively. Figure 2.3 shows the background measurements roadmap. It is easy to see from Figure 2.3 which programs depend on others, which are timely in relation to planned DSARC dates and the broad categories into which programs segregate themselves. An additional piece of information is shown by programs indicated with dotted lines; these are currently unfunded by any agency and are not planned for funding within the current budget plan submissions for whatever reasons.

To round out the Technology Program Plan, several additional pieces of planning-related information were included. Detailed schedules for all ongoing or planned programs that formed the basis for the Space Division Five Year Development Plan were taken directly from the budget submission package. Both standard and enhanced decision packages were supplied. Progress and accomplishments for ongoing PE63424F programs were summarized. Finally, program resources (financial and manpower), available facilities and required supporting organizations were listed.
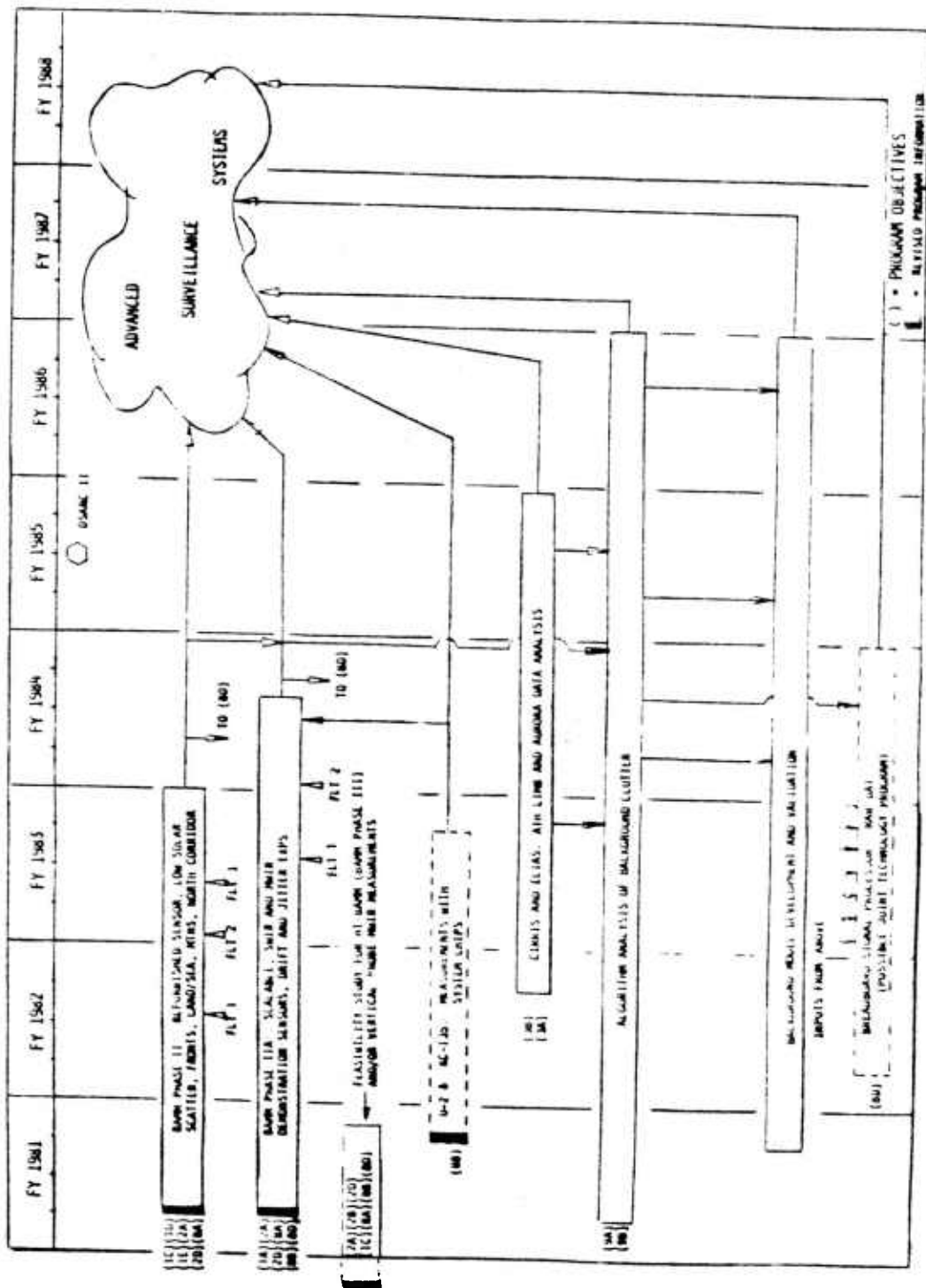
Figure 2.3 Background Measurements Roadmap

2.3.5   Revised (1981) Technology Program Plan

During calendar year 1981, ADI submitted the first
annual revision to the TPP. This consisted of a complete
replacement for one volume of the TPP and updates to the data
base volume. These documents are listed in Reference 3.

The three major revisions to the TPP were the addition
of an executive summary, a completely rewritten threat section,
and inclusion of a sizeable new data base covering the most
relevant NASA space sensor programs. Besides these changes,
the roadmaps and supporting programmatic information described
in the previous subsection were completely updated.

The executive summary provided a concise statement of
the utility of infrared measurement programs in general and
those programs being conducted under PE63424F in particular.
It was pointed out that measurement programs can identify and
quantify the phenomenology relevant to surveillance system
design, thus determining the feasibility of the basic concept.
They can provide validation of the proposed concepts by
demonstrating the technology and/or data processing necessary
for successful surveillance system operation. These
demonstrations can help to greatly reduce costly redesign of
both hardware and software during the fabrication phase of the
program and can help to ensure meeting all critical performance
goals for the surveillance sensor program, as well as
optimizing system design parameters before fabrication of the
actual sensor system is begun. Thus, these demonstrations
constitute a very cost-effective approach which can be
completed well in advance of the critical decisions concerning
implementation of a full-up system.

The two principal ongoing infrared measurement programs, BAMM and MSMP, are providing needed information in the areas of background and target phenomenology, respectively. Feasibility of the staring sensor concept has been demonstrated by data collected during BAMM flights. The completed and planned MSMP rocket probe flights are clarifying high-altitude plume phenomena which advanced surveillance systems must observe. Other programs are or will be addressing issues related to the use of measurements data in developing and validating models of background scenes and target signatures as well as demonstrations of currently available advanced infrared sensor technologies, especially focal plane and signal processing (data management) techniques.

The threat section of the TPP discusses those strategic targets which a space-based surveillance system must track. Currently, the term "threat" does not include any systems directed against the surveillance sensor which could degrade or negate its performance. Starting with the current Soviet threat, general trends were analyzed and the shape of future missile systems (1990-2000) was postulated. It was noted that SALT-type treaties could have a significant impact on the nature of the Soviet threat, since the numbers and types of missile systems which might be deployed could be limited.

The review of NASA space-based infrared sensor programs was conducted to determine if any were relevant to current missile surveillance measurement needs. As a starting point, only those programs concerned with earth or earth-limb viewing geometries and the 2 to 12 μm spectral region were considered. A data base of 37 ongoing or planned NASA programs meeting these criteria was assembled. The data base included sensor characteristics and an analysis of any potential application of each program to missile surveillance.

The net conclusion from this survey was that the current operational and planned future NASA spaceborne infrared experiments have little, if any, direct application to missile surveillance measurement needs and PE63424F objectives. There were several reasons for this negative finding. First, while the current focus of future surveillance systems is on staring mosaics, none of the surveyed NASA programs is equipped with a platform capable of making staring measurements. Most of the NASA systems scan as a natural function of the track of the spacecraft. Some additionally are provided with the capability of scanning normal to the spacecraft ground trace. Thus, the data obtained correspond to a totally different spatial frequency domain than that necessary for evaluation of the staring sensor concept.

A second reason for the negative survey is a mismatch in the spectral regions in which the data is taken. Missile surveillance needs are centered on the SWIR and MWIR plume emission bands for the BTH mission, and in the LWIR spectral region for ATH cold body tracking. The plume emission bands are centered in the deep absorption bands of the atmosphere. The majority of NASA's earth-looking IR experiments are aimed at either earth surface environmental and temperature determinations or trace gas and pollutant monitoring in the atmosphere. In the former case, the chosen bands are nearly always window bands (e.g., 8 - 11 μm), thus allowing the sensor to "see" to the surface of the earth. By definition, such data are out of the spectral region relevant to the missile surveillance background measurements needs. Bands employed for the trace gas monitoring also are generally removed from the desired plume emission band backgrounds.

Potential indirect or secondary benefits of NASA programs include supplying data for developing or validating

background models in spectral bands which could be extrapolated to the primary missile surveillance bands and in providing correlative meteorological or climatological information to supplement that collected by other measurement programs. For the future, it was suggested that joint NASA/Air Force measurement programs are an option which should be explored.

2.4   M46C Infrared Channel Analysis

During the first half of CY 81, ADI received technical direction from SD/YLVM to review the M46C sensor program to determine potential applicability to the missile surveillance measurements program. At that time, ADI was under contract to Sandia Laboratories to provide a preliminary focal plane design concept and performance estimate for the proposed IR channel. The results of this study were published in the report listed in Reference 4.

The analysis centered on the practicality and utility of implementing an IR channel on an advanced version of the sensor and estimating the performance of the proposed sensor for the missile surveillance mission. The proposed sensor design was obtained from the contractors involved along with the best estimate of spacecraft jitter motion. Since the sensor design had not been finalized, it was recognized that conclusions made at this time could change as the program evolved.

The basic approach involved analyzing both focal plane and overall sensor system performance (including detector, platform and clutter effects), identifying the major space segment issues and assessing ground data processing requirements and issues. The results were combined with the measurement goals of PE63424F to arrive at the final assessment of M46C utility for missile surveillance measurements.

Ten system and/or sensor issues were identified as critical drivers in utilizing the proposed M46C instrument for missile surveillance measurements. The major stumbling blocks to collecting data useful for advanced surveillance system design were spectral band, focal plane NET and system CET. In addition, improvements to the optics design could substantially benefit missile surveillance.

It was concluded that an additional or modified spectral band should be added in the MWIR region. This was not judged to be a substantial technical issue, but one of mission requirements and priorities. The estimated focal plane NET was too high for the proposed sensor to be of any real use for missile surveillance. Improved cooling, probably involving replacing the planned cooler with a passive radiator, would be needed. Similarly, predicted spacecraft jitter caused the estimated CET to be on the same order as the NET. This situation is unlikely to improve in the future, since it requires a major modification to the platform. A final point concerned the launch schedule. Any data collection and reduction would probably be too late to support currently planned decision milestones on advanced surveillance systems.

2.5   Issues Associated with the DSARC for Advanced Warning System

During CY 81, ADI reviewed for SD/YLVM the issues associated with the selection of an advanced, space-based, infrared missile surveillance system and to show the role of Program Element 63424F and the Joint Technology Program in addressing these issues. An assessment of the criteria regarded as most likely to be used in selecting the design of an advanced warning system (AWS) was presented. Critical

points not being adequately examined were especially noted. A report and separate briefing on this subject were published and are listed in Reference 5.

The analysis began with an historical background covering the evolution of the staring sensor concept. This covered a more than ten-year period going back to the early 1970's. The original motivation behind an advanced surveillance system was closely connected to the level of requirements for performing the attack assessment mission. In general, the rationale for pre-NUDET attack assessment (impact point prediction) was not as clear as that for the post-NUDET case for two reasons. The most significant difference was the brief amount of time to acquire, process, and use the information. The second difficulty was the lack of a strong quantitative link between mission utility and surveillance. Arguments have been presented to the effect that a massive attack would produce a response regardless of any sensor-supplied pre-NUDET attack assessment information, while a limited attack would be "ridden out" in any event.

Major programs undertaken in the 1970's and related to an AWS were the Air Force Mosaic Sensor Program (MSP) and the DARPA Mini-HALO program. The history, interactions and conflicts between the two programs were reviewed along with the emergence of sensor survivability as a major driver for an AWS. The latter was driven by a series of technological and political events including Soviet ASAT tests, the high energy laser threat and the attainment of nuclear parity by the Soviets.

In December 1979, a Defense System Acquisition Review Council (DSARC) examined five options for an AWS. The alternatives presented and the recommendations of the Council

were accurately stated and analyzed. The selected option was designed to provide major improvements in system survivability as expeditiously as feasible and with as high a level of confidence as possible. While mosaic staring sensor technology was judged to be high risk due to its relative lack of maturity, a joint Air Force/DARPA technology program (JTP) was called for to conduct technology developments, experiments and demontrations in support of an eventual space-based staring sensor.

With this background, the issues and likely prospects for the next DSARC were explored. In general, in the period since the November 79 DSARC few issues have changed and the trend of increasing emphasis on survivability and endurance has only gathered momentum. The negative findings of the DSARC concerning the maturity of onboard processing and focal plane technology appear to be equally valid two years later.

Study of the survivability issue noted that within the national political arena there are many indications that survivability is still the principal design issue for an AWS. This is seen in official policy statements at the secretary of defense and JCS level and at the program level. Four of the top five AFSC programs have strong survivability requirements. The SMSS study sponsored by DARPA and DCA is an example of the trend toward broadening the advocacy of the survivability concept to include endurance through the duration of a postulated strategic nuclear war.

On the other hand, the case for attack assessment capability is much less clear. Table 2.11 summarizes some of the issues for and against the utility of attack assessment. The spectrum of respected opinion on this issue is quite broad.

Table 2.11   Attack Assessment Controversy

PRO:

- GIVES NCA MORE OPTIONS FOR LIMITED RESPONSE

- FORCE MULTIPLIER FOR ICBM AND BOMBER LEGS OF TRIAD

  - LAUNCH THREATENED ICBMS
  - RETARGET RVs AWAY FROM EMPTY HOLES
  - REROUTE BOMBER CORRIDORS FOR MAX PENETRATION

- HELPS PROTECT NCA AND C^3

- HANDOFF IMPROVES ABM EFFECTIVENESS

CON:

- NCA HAS SIMPLE, BINARY DECISION -- IF LIMITED ATTACK, CAN WAIT FOR NUDET ASSESSMENT; IF MASSIVE ATTACK, CAN MAKE IMMEDIATE MASSIVE RESPONSE

- SIOP AND GUIDANCE TECHNOLOGY TOO COMPLEX FOR REAL-TIME RETARGETING

- VERY SHORT TIMELINE FOR ATTACK ON WASHINGTON D.C.

- ADVANCED ICBMs WITH LOW THRUST PBV AND MARV WILL DEFEAT PRECISION ATTACK ASSESSMENT

CONCLUSION: NO CLEAR CONSENSUS

At one end there is a group that believes the only useful pre-NUDET information is knowing whether survival of the land-based deterrent is threatened. If the attack were limited so that some threshold fraction of the ICBM force will survive, then one could wait for the IONDS system to provide post-NUDET assessment information. If the attack were massive, then the corresponding all-out response would be generated. This group sees no need for providing more detailed information than can be acted upon under the supreme stress of an anticipated impact of Soviet RVs on U.S. territory.

At the other end of the spectrum, there is a group which speaks of launching the threatened missiles located inside Soviet RV impact zones that have been predicted by an advanced surveillance system. The missiles would be retargeted in flight toward locations of unemptied ICBM silos or active command centers using attack assessment information. With advanced launch vehicles, mid-course abort signals could even allow harmless recovery of the warhead.

The conclusions regarding the need for attack assessment capability in an AWS were that a relatively low level of assessment could be useful but precision impact point prediction would not be cost-effective.

A set of five options likely to be presented at DSARC-II was developed and rated for their relative capabilities in the areas of survivability and attack assessment. The connection between the options and the current missile surveillance system was carefully made to show the strengths and weaknesses of each.

Finally, an assessment was made of the principal PE63424F measurement programs relative to the needs of an AWS. The data base needed before DSARC-II which could be supplied by

these measurement programs was developed and compared to the
likely near-term achievements. The need for a convincing
end-to-end simulation of staring sensor performance was
presented along with the role which measurements could play.
Table 2.12 shows specific deficiencies in the areas of
measurements, technology and systems work identified in the
study. If uncorrected, these are expected to adversely affect
the prospects at the next DSARC for an AWS employing a staring
sensor.

2.6   Interactions Among Measurements, AWS, and Teal Ruby
           Programs

           During the second half of FY 82, ADI was tasked to
further examine the AWS program and its relationship to the
measurements being performed under PE63424F. This effort
consisted of examining the current need for and the utility of
the BAMM and HPTEM programs in light of AWS requirements,
defining needed coordination between AWS and measurement
programs, and updating if necessary the study of DSARC-II
issues covered in the previous section. In addition, a study
was made of the utility of the Teal Ruby Experiment (TRE)
program for collecting data needed for the design of advanced
missile surveillance systems. All of this work was reported in
Reference 6.

2.6.1   Advanced Warning System Implications for Measurements

           This study examined the connection between current AWS
system concepts and technology development efforts, and the
BAMM and MSMP measurement programs. The system performance
requirements for the AWS program were used as a starting point
for the analysis. These were combined with the deficiencies of
the current missile surveillance system to indicate the need

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Table 2.12 Current Deficiencies Relative to DSARC-II

- MEASUREMENTS

  - DATA COLLECTION AND ANALYSIS FOR GENERATING BACKGROUND SCENES

  - SPATIAL AND TEMPORAL AURORA MEASUREMENTS (NUCLEAR ENVIRONMENT SIMULATION)

  - HEL LONG-PATH PROPAGATION

- TECHNOLOGY

  - *BACKUP FOR LPE HgCdTe FOCAL PLANE CHIP WITH INDIUM BUMP HYBRID

  - INDUSTRIAL BASE DEVELOPMENT FOR LOW-COST FOCAL PLANE ARRAY SERVING STRATEGIC, TACTICAL AND COMMERCIAL USERS

  - *PROCESSOR ARCHITECTURE AND HARDWARE

  - CLOSE COORDINATION WITH VHSIC AND SMATH PROGRAMS

- SYSTEMS

  - ALGORITHM DEVELOPMENT

*DEFICIENCIES IDENTIFIED AT DSARC-I

for an AWS. No assumptions were made about whether such a sensor would be a starer or scanner. Table 2.13 summarizes the results of this analysis by showing the impact of the generic design features proposed for an AWS on mission performance.

To properly design the AWS, measurements must be made using sensors which will see the AWS targets and background at significantly higher sensitivity and in the same spectral bands which may be used. The general spectral regions of interest are SWIR and MWIR.

To connect the measurements requirements to the AWS mission requirements, three basic AWS mission performance parameters were defined. The earliest reporting time (ERT) for attack involves identifying missile launch events as well as limited booster tracking. The principal measurement requirements to support the ERT mission parameter are background clutter measurements, missile radiance spectra in the SWIR band, missile flight dynamics near launch, and measurement of the ability of the sensor signal processor to distinguish targets from background clutter.

A second AWS mission requirement is circular error probability (CEP) of impact. This involves prolonged missile tracking. For this parameter, the principal measurement requirements are background noise, missile radiance spectra in the MWIR band, and detector/system noise characteristics. A third mission requirement, track number capability (TNC), relates the ability of the AWS to process the collected infrared data into a useful format. The TNC is determined primarily by the capabilties of the sensor and signal processor.

Table 2.13   AWS Rationale to Meet Current Sensor Deficiencies

DESIGN FEATURE	TECHNICAL REASON	MISSION RATIONALE
STARING MOSAIC FOCAL PLANE	REDUCED BACKGROUND	LOWERS DETECTION THRESHOLD
ADVANCED SCANNING FOCAL PLANE		SEES ALL THREATS REDUCES FALSE ALARMS
TWO COLOR DETECTION (SWIR, MWIR)	IMPROVED HIGH ALTITUDE SENSITIVITY REDUCES LASER THREAT	INCREASES TARGET TRACKING TIME SURVIVABILITY
ONBOARD SIGNAL PROCESSING	IMPROVES CLUTTER SUPPRESSION	LOWERS DETECTION THRESHOLD SURVIVABILITY

The results of analyzing AWS measurement needs are summarized in Tables 2.14 to 2.17 for the areas of target, background, detector and signal processor measurements, respectively.   For each of the general classes of measurements given in the tables, measurement sensor characteristics (footprint, sensitivity, temporal resolution, aspect angles, etc.) were derived based on expected AWS performance and system design requirements.   This set of measurement sensor requirements is given in Reference 6 and formed the basis for assessing the utility of existing data and sensors for supporting the AWS program.

The background data collected by the BAMM and RM-19 programs and the target data collected by the MSMP and TRIM programs were examined for applicability to the AWS program. The need for additional data collection was found to depend upon the level of performance required of the AWS system.   The principal measurements support required by the so-called

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Table 2.14   Target Measurements

MEASUREMENT	DATA	UTILITY
INTENSITY SPECTRA	(VS. ALTITUDE)	TARGET MAGNITUDE (FLT. PROFILE) BAND SELECTION TARGET IDENTIFICATION DETECTOR/TEMPERATURE SELECTION
	(VS. TIME) (VS. ASPECT)	WORST CASE TARGET MAGNITUDE TARGET INTENSITY VARIATIONS
	FLIGHT PROFILE	TARGET SPATIAL PSD TARGET DISCRIMINATION ALGORITHMS

Table 2.15   Background Measurements

MEASUREMENT	DATA	UTILITY
RADIANCE	SPECTRAL RADIANCE	DETECTION BAND SELECTION DETECTOR SENSITIVITY REQMT.
SPATIAL INTENSITY FLUCTUATIONS	PSD (SPACE)	MAGNITUDE OF CET CLUTTER SUPPRESSION ALGORITHMS
	EXCEEDANCE	FALSE ALARM RATE THRESHOLD FOR DETECTION
	RAW	BACKGROUND EMULATION TESTING
TEMPORAL INTENSITY FLUCTUATIONS	PSD (TIME)	ADDITIONS TO CET, NET MAG. CLUTTER SUPPRESSION EFFECTIVENESS

Table 2.16   Detector Measurements

MEASUREMENT	DATA	UTILITY
NOISE SPECTRA	NOISE SPECTRA	CONTRIBUTING MAGNITUDE TO NET DETECTOR MATERIAL SELECTION DETECTOR TEMPERATURE
D* UNIFORMITY	UNIFORMITY STATISTICS	FIXED PATTERN NOISE

Table 2.17   Signal Processor Measurements

MEASUREMENT	DATA	UTILITY
TARGET/BACKGROUND DISCRIMINATION	(VS. EMULATED BACKGROUND)	DISCRIMINATION EFFECTIVE-NESS CLUTTER SUPPRESSION THRESHOLD SET FALSE ALARM RATE ERT
TARGET TRACKING CAPABILITY	(VS. THREAT SCENARIOS)	DATA THRUPUT (T'D) ATTACK ASSESSMENT CEP

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.mum performance AWS design was found to lie in the area of
a reduction and analysis. However, increased AWS
:ormance levels were found to require additional target
') and background (MWIR) measurements. Both the data
.ity and schedule for these measurement activities are given
Reference 6.

,2   Updates on DSARC-II Issues

A small part of this study was directed towards
ating the report discussed in Section 2.5. This was
:erned with the issues associated with the DSARC on an
anced, space-based missile surveillance system. Several
itional comments concerning requirements for performing the
:ision attack assessment mission and for system
vivability were discussed in Reference 6 and are summarized
ow.

It was noted that the term "requirements" is often
i and frequently misinterpreted. There are many sets of
uirements in existence even within a single area like
sile surveillance. Frequently, requirements from different
rces are in conflict or are difficult to compare. In
ition, requirements can change in time due to political or
itary events. This poses a problem for sensor system
cepts which were designed to address one specific set of
uirements.

Several specific examples of conflicting requirements
ated to precision attack assessment were given in Reference
The conclusion was that the mere existence of requirements
s not automatically provide an advocacy for advanced
veillance system development. The implication for DSARC-II
that the existence of requirements which can be satisfied

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only by one of the advanced surveillance system options will not lead to that option being chosen. Considerable active support is needed from the source of the requirements to make an impact upon the selection committee.

As far as measurement programs are concerned, it was pointed out that they supply the information needed for sensor system development and do not directly address the issue of requirements. Given the present state of affairs regarding conflicting requirements and the somewhat limited goals of AWS system development, measurement programs must be innovative in proposing continuing efforts that will provide the best data for the broadest range of potential future systems.

In the survivability area, the Survivable Missile Surveillance Study (SMSS) was examined as a prime example of the continuing trend toward broadening the advocacy of the survivability concept. The SMSS has had a major impact in spurring the surveillance community to place a steadily increasing emphasis on the issue of sensor system survivability. It was felt that this program supports the conclusion of Reference 5 that survivability and not attack assessment capability will be a major driver in selecting the follow-on to the current missile surveillance system. It is expected that the strong legacy of survivability from the SMSS program will dominate the development of AWS concepts as compared to the ability of the system concepts to perform any stressing attack assessment missions unless the AWS program office takes positive action to provide specifications to do so.

2.6.3   Coordination Between Measurements and AWS Programs

The issue of coordinating measurement experiments with the AWS data users was addressed by outlining the need,

schedule and an evolving plan relating PE63424F with the AWS program. The object was to utilize existing measurements data to benefit the near-term design of AWS concepts.

The framework for this cooperative effort is given by the AWS decision milestones for technologies and concept development. All of this work must come together sometime prior to the 1985 DSARC. Careful analysis of current AWS milestones showed that some are too late to allow the necessary work to be completed by 1985.

Activities within the measurement program element (PE63424F) in support of AWS have been ongoing for several years. Some of the more recent programs have been BAMM and MSMP, while the earlier RM-19 and TRIM programs provided additional background and target data respectively. Considering only the accepted statement of need for a survivable, endurable missile early warning system, it has been shown that AWS need only detect and track the first and second stages of missile flight. Measurement data in the SWIR and MWIR bands of interest have been accumulated and, for the most part, have been reduced for use by those involved in the AWS program. Table 2.18 indicates that data which has been reduced/analyzed for use. While further analysis could be done on TRIM and TEM data, there appears to be sufficient background data available for system design as well as modeling work. However, as pointed out in Section 2.6.1, any requirements for the AWS to perform the precision attack assessment mission will require additional target (PBV) and background (MWIR) measurements with data reduction completed by January of 1985.

It was concluded that the prime support any near-term measurements program could give the AWS program would be to contribute to and/or ensure the early completion of a system

Table 2.18 Measurements Data in Support of Missile Early Warning (MEW) Surveillance Systems

DATA NEEDED	SWIR		MMIR	
	TARGET	BACKGROUND	TARGET	BACKGROUND
DATA NEEDED	RADIANCE INTENSITY SPECTRA	SPECTRAL, SPATIAL, TEMPORAL RADIANCE	RADIANCE INTENSITY SPECTRA	SPECTRAL, SPATIAL, TEMPORAL RADIANCE
MEASUREMENTS MADE	TRIM MSMP/TEM CURRENT MEW SENSOR	BAMM	TRIM MSMP/TEM	RM-19
ANALYSIS DONE	TRIM-INSUFFICIENT TEM-IN PROCESS	SUFFICIENT	TRIM-INSUFFICIENT TEM-IN PROCESS	SUFFICIENT

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simulation. This must include timely completion of the
necessary algorithms, as well as the target signature models
and large background scenes to be used. Of secondary impact
would be further analysis of existing data such as that from
TRIM and the timely completion of TEM data analysis.

Ongoing and planned activities within both measurement
and AWS program elements in support of the above needs were
reviewed. The effort to develop a detailed sensor simulation
was started by the AWS program in FY 82. The development of
high-fidelity, large-scale, digital IR scenes will form a key
element in the evaluation of AWS concepts by serving as the
inputs for testing proposed sensor and processing concepts. To
obtain as much realism as possible in the simulated scenes, the
target and background data obtained through the BAMM and MSMP
measurement programs should be used wherever possible.

Additionally, a hardware scene generator which will
turn the digital computer output into a source of photons
faithfully reproducing the features of the scene is also being
planned. This would enable a direct laboratory test of the
performance of a focal plane submodule coupled to a model of
the proposed onboard signal processor. This end-to-end
simulation of the AWS concepts should provide confidence that
the all of the subsystem performance goals have been met.

The most relevant and time critical tasks needed to
coordinate measurement efforts with AWS user community
interests are associated with delivering background and target
data useful for developing large digital scene simulations for
analyzing AWS concepts. The definition of such scenes is at a
preliminary stage which allows both measurements and AWS
representatives to provide and discuss their inputs and
viewpoints on this subject. A working group was proposed to
handle this effort.

If it is determined that additional measurements data should be collected to support the AWS program, recommended sensors were BAMM II, Hi-CAMP II and/or Teal Ruby.

2.6.4 Potential Teal Ruby Contribution to Missile Surveillance Measurements Needs

Due to limitations on resources and the types of measurement platforms available to the MST program element, there has been continuous interest in recent years by PE63424F management in exploring the potential contributions of DoD and other agency programs to MST measurement data needs. One program of considerable interest is the DARPA Teal Ruby Experiment (TRE). During this study, ADI closely examined the Teal Ruby program to ascertain if contributions to MST measurements objectives could be found.

Two general areas of potential TRE contributions were explored: background measurements, particularly of earthscene clutter, and target signatures. Specific background experiments useful for PE63424F were proposed, while, in the target signature area, relevant previous analyses by other organizations were reviewed. All of these subjects are summarized below.

Some of the major reasons for examining Teal Ruby were that it is a space-based staring mosaic sensor and that it possesses spectral bands of direct importance to MST. However, many other issues are involved in trying to utilize TRE to conduct experiments. The analysis contained in Reference 6 carefully examined the impact of orbital altitude, step-stare operation, specific spectral band, footprint, field-of-view, sample time and instrument sensitivity before proposing specific experiments of benefit to the MST program.

It was found that, for the most part, TRE has the sensitivity to obtain the required quality of background data to meet missile surveillance measurements needs. Two specific below-the-horizon (BTH) background measurements were proposed. The first was characterizing the temporal fluctuations of the earthscene by using the R13 MWIR band on TRE. This would complement data already collected by the BAMM program in the SWIR spectral region.

The second proposed BTH experiment would measure a midlatitude maritime scene primarily in the R1 SWIR band. The data are required to resolve key issues with respect to early and high confidence (high probability of acquisition, P_A; low probability of false alarm, P_{FA}) acquisition of SLBM launches, particularly the SSN-6. Consequently, the scene should be representative of either Atlantic or Pacific SSN-6 launch areas. The experiment will furnish both spatial and temporal statistics of this background scene.

Analysis was also performed of the capability of TRE to collect above-the-horizon (ATH) data relevant to the MST program. Currently, two ATH missions are planned for Teal Ruby. These cover auroral activity (experiment B11) and the daytime earth limb (experiment B12). A number of problem areas were found for these proposed ATH observations.

The major drawback is sensor sensitivity vs sample time. To achieve adequate sensitivity to make meaningful measurements, the sample time is too long to yield data at temporal frequencies applicable to missile surveillance measurement needs. This conclusion is based primarily on theoretical ATH background models and on predicted TRE NESRs.

As definitive TRE test data becomes available, a more accurate conclusion can be made. The data available at the present time indicate that TRE experiments B11 and B12 are at best marginal in terms of payoff for current missile surveillance measurement objectives.

In the target signature area, three basic target measurement missions have been identified as being attractive to address missile surveillance measurement needs: a Minuteman launch; shuttle RCS burn; and ground static tests. These have been previously analyzed by Rockwell and Aerospace. The utility of each of these experiments is reviewed in Reference 6.

Table 2.19 presents a qualitative comparison of all of these experiments. Entries under the PE63424F Data Need Priority column in Table 2.19 reflect the priority of the measurement objective and are taken from the PE63424F TPP. Under the Data Quality/Utility column, each proposed mission is assessed as to the applicability to the missile surveillance measurement. In the Risks columns, qualitative assessments of risk are entered to indicate how feasible the mission is, whether modifications to TRE are required and the complexity of the logistics and inter-agency coordination necessary to execute the mission. Based on the data in Table 2.19, the proposed MWIR Temporal Scintillation, the Maritime Backgrounds and the Non-standard Propellant Static Firing missions appear most desirable from a benefit/risk standpoint. All three of these potential TRE missions in support of PE63424F objectives have high utility, are relatively easy to implement, require no modifications to the TRE sensor or spacecraft and require little or no inter-agency coordination. The one exception to this latter point is the static firing mission which would require coordination and timing with the organization conducting the ground test.

Table 2.19 Qualitative Benefit/Risk Summary of Proposed TRE Missions in Support of Missile Surveillance Measurement Needs

Proposed TRE Mission	PE63424F Data Need Priority	Data Quality/ Utility to PE63424F	Risks		
			Mission Feasibility	TRE Modification	Logistics/ Coordination
MWIR Temporal Scintillation	High	High	Low	Low	Low
Maritime Backgrounds	Med-High	High	Low	Low	Low
ATH Aurora TRE B11	Medium	Low	Med-High	Low	Medium
ATH Limb TRE B12	Medium	Low	Low	Low	Low
MMIII Launch	Medium	Medium	Medium	Low	Medium
Shuttle RCS Burns	High	Med-Low	Med-High	Low	High
Static Firing-Standard Propellant	Low	Med-High	Low	Low	Med-Low
Static Firing-Non-Standard Propellant	Med-High	Med-High	Low	Low	Med-Low

3.0 ANCILLARY ACTIVITIES

In addition to the previously reported major studies, numerous supporting activities were conducted during the contract period. These included formal and informal reviews, meetings and short studies on problems of immediate interest. This work is summarized below in sufficient detail to reflect the type and level of activity performed.

3.1   Acquisition Plan for Advanced Space Application Program

From March to July 1979, ADI provided support to SAMSO/YCD in developing the acquisition plan for the Advanced Space Application Program (ASAP). ASAP was to be a technology development effort leading to an operational surveillance system for the detection of air vehicles and other surface or atmospheric targets.

The program contained new efforts which are described in greater detail in the tabs of the development plan on file at Space Division/YL. They included AVD/Teal Ruby Data Analysis (Appendix A), AVD Technology and Concept Development (Appendix B) and SBR Technology and Concept Development (Appendix C). Technology programs to be done by other agencies were covered in Paragraph 5.4 (and are listed below for reference). The new programs were identified by the combined effort of the Advanced Space Applications Program Office and Advanced Space Development Program Offices in close coordination with Defense Advanced Research Projects Agency (DARPA) Strategic Technology Office and the Office of the Under Secretary of Defense, Research and Engineering (USDR&E). Invaluable support was provided by Air Force laboratories, particularly the Air Force Geophysics Laboratory (AFGL), in the consideration of phenomenologies and technologies. Program

planning activities were coordinated closely with Air Defense Command (ADCOM), Tactical Air Command (TAC) and Strategic Air Command (SAC). Planning and technical information has been exchanged between related program efforts as depicted in the DoD Spaceborne Infrared Technology Plan, dated September 1977. The plan, directed by OASD(I)/DDI, identifies all long-range system development schedules that could capitalize on IR technology programs related to missile launch detection, cold body detection and air vehicle detection missions. It also includes airborne and spaceborne measurements programs that provide a data base and component feasibility testing information.

ADI assisted SAMSO/YCD in developing a procurement strategy supportive of PMD direction/guidance regarding the aerospace vehicle detection mission. This involved drafting many versions of a program plan for multi-agency coordination and included developing program content, milestones and suggested allocation of funding to various types of tasks. Risk assessments were performed for SAMSO and inputs from contractual efforts were evaluated and coordinated with DARPA/STO and ADCOM. A draft of a USAF briefing to ADCOM was developed for SAMSO/YCD explaining the IR and Radar mission concepts, including an upgraded plan that could perform the cruise missile warning mission for the early 1990's. Primary consideration during the planning phase of this program was given to the need to provide ADCOM with a survivable aerospace vehicle surveillance capability to support the missions of strategic force survival and defense of U.S. air sovereignty. This need required the investigation and development of improved surveillance concepts and advanced technologies. The ability to increase U.S. offensive force effectiveness would satisfy a corollary need of SAC.

ADI was requested to, and did, participate in the Joint United States Canadian Defense Study (JUSCADS) Core Group Review of the ASAP plan.

3.2   BAMM IIA Program Support

During FY 81 and 82, ADI attended numerous meetings and provided inputs to SD/YLVM on several technical issues related to the BAMM IIA program. During this period, the design of the new balloon platform was begun, one of the two proposed sensors passed PDR and CDR milestones while the other was terminated, and preliminary mission planning meetings were held. Specific ADI support activities in these three main areas are discussed below.

3.2.1   Sensor Design

Prior to the preliminary design review (PDR) for the sensor currently in fabrication, ADI attended several technical interchange/technical direction (TI/TD) meetings and reported on outstanding issues to YLVM. Questions of what spectral bands should be used and how the filter specifications should be written for the manufacturer were extensively discussed. Band selection in the MWIR region was particularly controversial because of the platform operating altitude. After several iterations, a compromise set of bands was approved. It was pointed out that properly specifying filter passband cut-on and cut-off slopes can keep the cost affordable and allow for meaningful data interpretation. Methods of specifying these quantities were suggested to YLVM.

PDR was held in June, 1981 and the critical design review (CDR) in November 1981. Prior to and during these reviews, ADI discussed several design and hardware issues with

government and contractor personnel to emphasize likely problem areas and suggest ways of avoiding future difficulties.

In the optical subsystem area, it was felt that the information presented at the CDR was insufficient to confidently proceed with fabrication. Specifically, it was recommended that a complete and consistent set of optical prints was needed, test plan release dates should be supplied, cryogenic testing of the telescope should be done, the effects of non-uniform focal plane illumination should be analyzed and single crystal material must be used near pupils to insure wavefront quality.

Other issues raised included sunshade and off-axis rejection performance, the effects of sub-pixel blur on point-target data collection and how sensor noise equivalent bandwidth was being defined.

During FY 81, ADI also provided the same type of technical support on a second BAMM IIA sensor design. However, this program was cancelled following PDR.

3.2.2   Sensor/Platform Interface

As part of the BAMM IIA program, a new balloon platform is being built. Several interface meetings between the platform and sensor contractors (originally 2 contractors, later reduced to 1) were held from June to November 1981. ADI attended all of the meetings and worked with both the contractors and the Air Force to ensure that the most useful platform design was implemented.

Early-on, the basis for an interface control document (ICD) was developed. Since the sensor designs were underway

before that of the platform, it was imperative that the platform design accommodate these while not unduly restricting the design of sensors yet to be built under future programs. A comprehensive outline of an ICD was agreed to by all parties. Strawman specifications for the platform and platform-sensor interfaces became hard numbers as the designs proceeded and the needs of all the principals became better known.

The most critical platform design issue which ADI provided inputs on was the pointing and motion compensation system. This is the key to collecting background data useful for staring sensor design. Definitions of the available degrees of freedom for sensor pointing and gimbal controls of the line of sight were worked out so that experiment planning could be started.

3.2.3   Mission Planning

During the platform/sensor interface meetings, it became apparent that there were many unanswered questions concerning the planning and conduct of BAMM IIA experiments and post-flight data reduction. ADI suggested that planning begin on these issues as soon as possible to make first-flight success a reality. Although the program schedule has been eased somewhat by slipping the initial flight from spring to fall 1983, considerable planning still remains to be done.

ADI was in a unique position to constructively comment on mission planning, since an ADI staff member was formerly mission controller on the BAMM program. Past experience indicates that having the sensor contractor directly responsible for both pre-flight integration activities and for operating the sensor during the flight is essential to a

successful mission. Since it was not clear that such would be
the case for BAMM IIA, this course of action was recommended to
YLVM.

The need for a technical director to pull together
pre-flight experiment planning and sensor integration
activities, to conduct the actual experiments and to smooth the
way for efficient post-flight data analysis was strongly noted
by ADI. Such issues as the type of equipment to be available
in the support trailer van and the real-time sensor data needs
require a technical director for efficient resolution. It was
noted that the role of a technical director is completely
distinct and separate from command/control of balloon flight
operations to which personnel are already assigned.

Data analysis was also noted by ADI as an area
requiring extensive preparation and pre-flight testing.
Converting wide-band analog data to digital tapes can be an
involved process. Since a wider range of data reduction can be
performed with the BAMM IIA sensor data, more software needs to
be developed. This is an expensive process and should be
planned well before the actual data reduction takes place.

3.3   Multi-Spectral Measurement Program (MSMP) Support

MSMP is designated to measure the spectral, spatial
and total radiant intensity characteristics of low thrust
rocket engines at altitudes over 150 km. The measurements are
to be in the Short Wavelength Infrared (SWIR), Medium
Wavelength Infrared (MWIR), Long Wavelength Infrared (LWIR),
Ultraviolet (UV), and Vacuum Ultraviolet (VUV) regions of the
optical spectrum. The measurements data will be used to
provide an accurate assessment of the required bandpasses and
thresholds used in the design of an advanced surveillance,

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detection, warning, and tracking system. These data are needed
to determine: (1) the feasibility of Long Wavelength Infrared
(LWIR) for small target detection and tracking; (2) the
trade-offs of SWIR and MWIR bandpasses for low thrust rocket
engine plume detection and tracking; (3) the feasibility of UV
and VUV for upper stage missile detection and tracking
applications; and (4) aid in the interpretation of data being
obtained by current classified systems. The measurements are
obtained by launching a target engine module and a sensor
module on the same rocket. After booster burnout, the modules
separate from the rocket and then from each other. An RF
tracker in the sensor module points the sensor at the target
engine while the engine performs 5 motor burns.

In July 1980, at the request of Space Division/YLX,
ADI performed a cost analysis of the planned High Performance
Target Engine Measurements (HPTEM) program. This included an
evaluation of the various launch option costs and an analysis
of the several instrument package development costs.

A full report on issues concerning HPTEM launch
support and a revisit of cost estimates was required of ADI by
Space Division/YLX and YLV in October of 1980. ADI provided a
study outline of issues and risk considerations (Table 3.1) for
approval by SD/YL. A completed analysis of the issues was
presented to SD/YLV and the accepted option costs were
developed, compared and presented to SD/YL. ADI continued to
support YLX through several meetings during which the results
of the analysis were presented to higher management at YL.

3.4   Conference Paper

ADI prepared the draft of a technical paper and the
viewgraphs used to present the material at an SPIE conference

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Table 3.1 HPTEM Issues

I.   OPTIONS

     A.   LAUNCH VEHICLE

          1.   MMI - 2 STAGE

          2.   MMI - 3 STAGE

          3.   THOR

     B.   LAUNCH SITE

          1.   MECK ISLAND

          2.   VANDENBERG AFB

               A.   PAD 2

               B.   PADS 3

               C.   ABRES MM (HOLE)

               D.   SLC PAD (THOR)

     C.   PAD CONFIGURATION

          1.   ABOVE GROUND LAUNCH

          2.   BELOW GROUND LAUNCH

     D.   LAUNCH SUPPORT

          1.   ALL AIR FORCE CREW

          2.   ABRES/CONTRACTOR CREW

          3.   SPACE DIVISION/AEROSPACE/AFGL/CONTRACTOR CREW

          4.   INDEPENDENT CONTRACTOR CREW

     E.   RECOVERY

          1.   AIRBORNE

          2.   WATER

          3.   AIRBORNE/WATER BACKUP

II. CONSIDERATIONS (RISK)

    A. AVAILABILITY (PHYSICAL, SCHEDULE)

        1. LAUNCH VEHICLE

        2. SITE

        3. ERECTING EQUIPMENT

    B. NEEDED MODIFICATIONS

        1. SITE

        2. ERECTING EQUIPMENT

    C. TECHNICAL PERFORMANCE

        1. LAUNCH VEHICLE

    D. CREW EXPERIMENT

        1. MANAGEMENT

        2. TIMING/SCHEDULE

        3. COMPOSITION

            A. OLD vs NEW

            B. CIVILIAN vs MILITARY

    E. COST

    NOTE: DELAY COST CONSIDERATIONS UNTIL OPTIONS ARE
           NARROWED

III. SELECTED OPTIONS

    A. MMI/Z STG; V.A.F.B. ABRES "A" SITE, PAD 3 ; ABOVE
        GROUND

    B. SPECIFIED LAUNCH INTEGRATORS (SEE TABLE)

Table 3.1 HPTEM Issues (cont.)

IV.   COST COMPARISON (LAUNCH SUPPORT ONLY)

    A.   FACILITY PREPARATION (ON-SITE)

    B.   FACILITY ACTIVATION

    C.   LAUNCH SUPPORT

    D.   FACILITY REFURBISHMENT

    E.   HOUSEKEEPING

    F.   DOCUMENTATION DEVELOPMENT

V.   RECOMMENDED OPTION

    -   SPACE DIVISION/AFGL/AEROSPACE LAUNCH TEAM

    -   MMI/TWO STAGE

    -   ABRES "A" PAD 3 ; ABOVE GROUND

in August 1981. The presentation was made by SD/YLVM personnel. The paper was published in the conference proccedings as listed in Reference 7.

The paper discussed the value and importance of infrared measurement programs. It showed that the utility of military infrared measurement programs has been and continues to be in the support of concept development, design, and operation of surveillance systems. This is especially true in the specific area of space-based missile surveillance through the detection of infrared radiation during all phases of missile flight. Throughout the last few decades there have been numerous measurements programs treating a wide variety of issues in infrared target and background phenomenology for operational systems. This type of measurements support will be even more important in the future in the face of evolving threats, increased requirements on surveillance systems, and developing technologies which need demonstrations of their capabilities before full-up surveillance systems can be designed and fielded.

The types of support which measurement programs can offer to advanced surveillance concepts include basic feasibility demonstrations of the proposed concept as well as guidance in selecting key system parameters like spectral band, sampling rate, footprint, and sensitivity. Judiciously planned measurement programs can provide critical data in support of the system at a fraction of the cost of a trial-and-error approach, which for a space-based system implies a new or modified satellite and sensor for each trial.

Three categories of prime importance in developing effective measurement programs were discussed. Target and background measurements are the main types of actual data which

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measurement programs can supply to surveillance system concepts. In the target signature area, the largest uncertainty concerns the post-boost vehicle (PBV). This problem is currently being addressed by the missile surveillance measurements program. In the background measurements area, validation of the staring sensor concept requires knowledge of the spatial and temporal characteristics of the earthscene. Data collected by the YLVM BAMM program has helped to resolve some of these issues.

For the design of surveillance systems, a very useful synergism exists between measurements programs and the development and exercise of phenomenological models. Models of target and background scenes of interest are required to generate the large data base needed for simulating the performance of the proposed surveillance system under a wide variety of operational conditions. There is a clear need for measurement data to support the development of the models. Even for cases where the phenomenology is fairly well understood, the models impose measurement needs of their own for calibration and validation of their predictions. In many cases, measurements are required simply in an attempt to identify and understand the fundamental phenomena involved.

The second major category of measurement programs is technology demonstration. The capabilities of available advanced technologies can be validated under quasi-operational conditions with suitably designed measurement tasks.

One major technology emphasis at this time is that of infrared mosaic focal planes. Several competing approaches to developing a focal plane capable of use in a staring sensor are now in laboratory development. Based on the components available today, it is feasible to assemble a sensor with a

mosaic focal plane and field test the device for performance under conditions duplicating portions of a mission such as missile surveillance.

One YLVM measurement program plans to fly such a focal plane on a balloon platform to collect background data. This approach involves a relatively small cost and offers the capability to test other designs at low cost with a relatively quick turnaround.

The third principal area of measurement program support concerns the critical issue of data management for large array mosaic focal planes. In such a mosaic, very large numbers of detectors are required for coverage of the earthscene of interest. Therefore, either a much bigger data communications link than is currently used with scanning sensors is required or onboard signal processing must be developed. The latter approach has several advantages including reduced ground terminal size and less susceptibility to jamming with a narrow-band downlink.

Development of the onboard processor approach involves several areas: computer architecture, software, and hardware. Design work is proceeding in all of these areas. During the long development period required for new full-up surveillance systems a measurements program is an appropriate vehicle for demonstration of many of these aspects of the onboard data management problem. Once the architecture, software and hardware designs have been set, it is very difficult and expensive to change to an alternate approach. Given the long lead time from design selection to actual flight, early measurements support is essential. This can take the form of ground-based laboratory programs to prove the architecture concepts or actual flight tests of a subscale sensor with

onboard processor hardware. While the latter is the most
sophisticated approach to demonstrating new sensor concepts
and, historically, has not been common for measurements
programs, it now appears that this approach is very useful and
possibly even required.

3.5   Other Supporting Activities

This section highlights a wide range of miscellaneous
activities which took place over the entire contract period.
They are indicative of the type of continuous, real-time
support which ADI provided to Space Division.

On an annual basis, YLVM conducts a review meeting of
all measurement-related activities. ADI supported several of
these and presented an overview of ongoing and planned work
directed by ADI's contract tasks. The meetings were also a
productive time for obtaining inputs for the Technology Program
Plan from members of the measurements community.

Several times during the contract, questions were
raised by higher headquarters about measurement program
objectives, long-range plans and needed funding. Using the TPP
as a basis, ADI supplied the requested data to YLVM in a timely
manner.

Proposed utilization of the Air Force Malabar facility
(OL/AJ) which is under the control of SD/YL was addressed in
several meetings with site personnel. The facility was visited
twice. Possible measurement-related experiments which would
make maximum use of Malabar's unique capabilties and likely
community interest in such experiments were discussed. These
included laser experiments and utilization of the DARPA Teal
Amber imaging chip in the operational telescopes.

Prospects for involving measurement users other than
Space Division in YLVM programs were explored in meetings with
the Rocket Propulsion Laboratory (RPL), Defense Nuclear Agency
(DNA) and Foreign Technology Division (FTD). RPL program plans
were included in the TPP and closer cooperation between RPL and
SD, including writing a new memorandum of agreement, was
discussed. DNA measurement programs covering auroral phenomena
were reviewed, the needs of SD in this area were presented and
the TPP was given to DNA to keep that agency appraised of YLVM
activities and plans. FTD measurement needs and activities
were outlined at several meetings including one at their
headquarters. A clear picture of their interests was obtained
and possible YLVM activities were defined which would mesh with
FTD data needs. The channels of communication between SD and
FTD were maintained such that useful exchanges continue to take
place.

Finally, YLVM was kept informed of ADI activities
conducted under other contracts which were closely related to
missile surveillance measurement programs. These included work
performed on the DARPA Mini-HALO, Teal Ruby, and Hi-CAMP
programs as well as the joint DARPA/AF JTP program. The
Hi-CAMP measurements program was of special interest, since it
is currently undergoing sensor redesign and its use as a
complement to current YLVM programs has been proposed.

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